# ELECTRICITY IN COAL MINING

# ELECTRICITY

IN

# COAL MINING

BY

DAVID R. SHEARER, E.E.
MEMBER AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
239 WEST 39TH STREET, NEW YORK
6 BOUVERIE STREET, LONDON, E. C.
1914

THE · MAPLE · PRESS · YORK · PA

# PREFACE

Many good engineering handbooks are to be found dealing with the details of electrical construction and the installation of mining machinery but the writer feels that there may be a demand for a small treatise covering, in a general way, the many phases of electrical engineering as applied to coal mining. Such a book would probably be of use to the investor or the operator in outlining methods of procedure and to the operating engineer in tracing the foundations upon which an electrical power plant may be established and operated in the most efficient manner.

In securing data upon which some of the machinery is described and for many of the photographs from which cuts have been made the writer wishes to acknowledge the help of the General Electric Co., Westinghouse Electric and Manufacturing Co., Goodman Manufacturing Co., Jeffrey Machine Co., and other manufacturers who have assisted in the work.

The writer also wishes to acknowledge his indebtedness to the Editors of *Coal Age* for manuscript corrections and to the McGraw-Hill Book Co. Inc., for the able manner in which the work of publishing has been carried out.

KNOXVILLE, TENN.
*September*, 1914.

# CONTENTS

# ELECTRICITY IN COAL MINING

## CHAPTER I

### INTRODUCTION

Electricity has been used for many years in operating mine signal systems as applied to hoisting equipment and for the purpose of communicating with the interior of mines from the surface but it has been a short time only since electrical machinery, as applied to the actual mining operations, justly made for itself a place in this field. However, from a very modest beginning, this form of power has increased in use and value to such an extent that many modern coal mine operators are utilizing it in every possible manner with marked economy and satisfaction. This extended use of electrical power has necessitated an especial study of electrical equipment used exclusively in and about mines.

Several methods of power transmission have been thoroughly tried out in mining work, such as the direct or cable drive, compressed air, steam and even systems of shafting operated by the engine upon the surface but nothing approaching electricity in ease of operation, efficiency and flexibility has been discovered so far.

Naturally the central point of any power distributing system is the prime mover or point where mechanical power is produced by coal or a water fall, or, in the case of the use of central station power, the substation. This transformation from mechanical power to electricity is easily made with an efficiency comparatively high depending upon the completeness of the mechanical equipment or the refinement of the machines in use.

The problem then becomes one of power transfer, for not being able to move the many places of the mine requiring energy in some form to the power house, we must move or transmit the power required to the scattered points of the operation where it may be used with advantage and economy.

Two factors will influence the selection of a method of trans-

mitting the energy developed at the power house to more remote points; first cost and efficiency.

At first all efforts were made to do this mechanically by systems of belting, shafting and pulleys as previously mentioned but this method lacked flexibility and the operating efficiency at all times low, rapidly decreased with distance and with the increased complexity of additions.

Steam has been used with some success but condensation losses are large if the pipe lines are of any considerable length and at best the small steam engine is extremely inefficient.

Compressed air is used to some extent and while not subject to condensation losses as are steam lines, it is not economical for great distances on account of pipe-line friction, leakage at joints and the inefficiency of air motors and compressors. It is well known that considerable heat is generated in an air compressor and this naturally decreases efficiency and hence detracts from any advantage in the use of air. By reference to those mines using compressed-air locomotives, we discover that the cost per ton mile of coal moved is considerably higher than is found to be the case when electrical equipment is employed. On the other hand, electricity offers most interesting possibilities, requiring as it does only a wire or system of wires for the efficient transmission of power to great distances.

Beginning at the power house, it is possible to convert the mechanical energy of the steam engine or water wheel into electrical energy with a small loss as compared to any other method of power conversion. The electricity may then be transmitted over wires, far less expensive than any system of piping to distant points of power application, and there be reconverted into mechanical power and applied to useful work. Several features of the electrical distribution system merit the closest attention as will be shown subsequently.

A central plant may be established containing all the prime movers, boilers and accessories necessary for the production of power on a large or small scale and in the most economical manner possible: this energy may be transmitted at little loss to any point in or about the mine and there used: the wires are inexpensive, easy to erect or move and if properly installed

their upkeep is small. Electrical machinery is efficient, flexible and light in weight when compared with the power developed: at any point reached by the electric wires light and heat may be secured as well as mechanical power.

The rapid adoption of electric distribution as applied to mining has been due chiefly to the features of merit just mentioned. There is no doubt, however, that a part of the advance is creditable to the efforts of engineers and manufacturers in developing sturdy and efficient electrical mining machinery and to the operators for the data collected and tests made leading to the more perfect operation of this type of equipment.

With all this growth, however, the use of electricity in mines is not receiving the attention from mine owners and operators that it should, or that it would if every operator were alive to the more recent developments and to the methods of securing maximum economy and production. Many operators, having a complete installation of electrical equipment know nothing of fundamental methods for increasing the efficiency of the machines they use or of decreasing the upkeep cost. Many mines at the present time requiring hoisting machinery still use a separate steam plant for this purpose only when for ease of control and rapid economical operation no form of winding mechanism can approach a modern electrically operated system. Steam pumps and steam-driven fans are still used to a great extent, notwithstanding the fact that electricity would make a more flexible and more economical power for both purposes. Adequate ventilation is often impossible without two or more fans located at widely scattered points and while these are easily driven electrically from the central station, it is necessary to use entirely separate engines and if the distance is great separate boilers for each fan when driven directly by steam.

Mine lighting has not received the attention merited by its prominence as an element in economical operation and much is left to be done in many ways whereby the use of electricity may be made an advantage or a saving in the cost of production. Not the least factor to be considered in this connection is safety of life and property and the reduction of an ever-present fire hazard.

Mine operators, like many other producers are wasteful and in a sense careless but this will be remedied when due thought is given to the conservation of life, health, property, production and power; a fact that will be forced upon us all as succeeding generations use with a lavish hand all that nature has given us and them.

It is with the primary ideas of conservation and economy that we consider the many phases of electrical development as applied to coal mining.

It is a lamentable fact that few mine operators give to their electrical plant the attention justly due, either as to its layout and equipment or to its operation and upkeep. Frequently in their efforts to secure economy in power plant costs the owners install inadequate machinery in an improper or incomplete manner and place this equipment in the care of men limited in both training and experience. Although these men may do the best they know how and give conscientious attention to their duties, such a course necessarily leads to expense, inefficiency and often to extensive repairs necessitated by burnouts, breakage or wear of the power plant machinery and its accessories. Of course, accidents occur and are unavoidable but if the entire plant equipment is properly designed, is of standard quality, correctly installed and carefully managed by experienced operators, little or no trouble may be expected and operation cost plus upkeep expense will be a minimum. Not the least point to consider along this line is the employment of a trained, experienced engineer to prepare the preliminary designs and supervise the entire installation.

In succeeding chapters, the writer will attempt to outline in a brief way the most important precautions to be observed in securing uninterrupted and economical operation of electrical coal-mining equipment from the initial plant design to the operation of all the power house accessories. However, due to the fact that many mine layouts are inherently wrong, it may not be out of place to consider the proper design and selection of machinery for certain variable conditions. Naturally every mine has an individuality of its own and no one certain type of electrical installation can be found best fitted for a given set of

conditions. On this account, owners preparing to develop should be very careful in securing the proper initial installation, to adequately meet the conditions encountered in their particular mines. At the same time they should so arrange the entire layout that future extensions or enlargements can be effected easily and without great expense. If possible the wiring system and operating machinery should be so interlocked that the failure of any one part would not necessitate a complete shutdown and would leave in operating condition the remainder of the plant.

Before taking up in detail the operation of mining equipment it will, in all probability, be well to review briefly some of the fundamental relations of the electric circuit and as many students become confused when considering both direct- and alternating-current calculations, a separate chapter will be devoted to each so that useful comparisons may be drawn and yet the fundamentals of each variety of current be kept distinctly in mind.

## CHAPTER II

### DIRECT-CURRENT CALCULATIONS

It is presumed that the reader is acquainted with the fundamentals of direct or continuous current but a brief outline of the characteristic features will be here given.

A direct current of electricity may be compared to the steady flow of a stream of water in a pipe line and in the same manner electrical action may be compared, for clearness of conception, to hydraulic phenomena as follows:

The pressure of the supply of electricity is measured in volts and can be compared to the pressure in pounds per square inch in a water or steam pipe. Thus, we say a generator works at a pressure of 250 volts just as we would speak of a boiler working at 80 lb. As an example, the electrical pressure or voltage of an ordinary dry cell is 1.5 volts, of a storage cell 2 volts; of the standard lighting circuit 110 volts and of the usual mine supply system 250 volts, although in some of the older installations a pressure of 500 volts is still used.

The flow of an electrical current or quantity per unit of time is measured in amperes and may be compared to the flow of a stream of water in gallons per minute.

Resistance is measured in ohms and may be compared to the friction of the water pipe tending to restrict flow.

Certain dependent relations may also be compared hydraulically for instance, the higher the voltage the greater will be the flow of current through a given wire, just as more water will flow through a given pipe if the pressure is raised; also, just as the friction on a pipe increases in proportion to the length and varies in inverse proportion to the cross section, so the resistance of a wire increases directly with the length and inversely with its cross-sectional area.

The fundamental law of the electric circuit known as the Ohm's law is: $I = \frac{E}{R}$. Where $I$ = current in amperes, $E$ = electrical pressure or voltage and $R$ = resistance measured in

ohms. This formula or law may be transposed to other forms, viz.; $IR = E$, $R = \frac{E}{I}$.

The power of the circuit is $IE$ in watts and as the watt or $\frac{1}{746}$ horse power (h.p.) is an extremely small unit the kilowatt (kw.) or 1000 watts is more generally used in rating power installations. Now, as 746 watts = 1 h.p. and 1000 watts = 1 kw., then 1 kw. = 1.34 h.p. nearly. As an example, what is the theoretical horse power of a motor requiring 14 amperes at 110 volts?

SOLUTION: H.p. $= \frac{I \times E}{746} = \frac{14 \times 110}{746} = 2.06$

A definite amount of power is always lost in forcing the current through any conductor, the amount lost, of course, being proportional to the resistance of the circuit. This is usually known as voltage drop or lost volts and the actual power or wattage thus dissipated is easily computed. Example: The resistance of a line of wire is 2 ohms, the voltage at the sending end is 110 and the current forced through the wire is 5 amperes. What is the voltage drop at the receiving end and the power ost in the line?

SOLUTION: $I = \frac{E}{R}$ or $E = IR$ $E = 5 \times 2 = 10$ volts lost.

$110 - 10 = 100 =$ voltage at receiving end.
Power lost $= I \times E = 5 \times 10 = 50$ watts $=$ $\frac{1}{14}$ h.p.

By substitution in watts lost

$$I \times I \times R = \text{watts lost or } I^2R$$

In calculating actual mechanical power produced by an electric current of given voltage we must further consider another factor, the efficiency of the generator or motor. This means that there is some loss in converting mechanical energy into electricity or electricity into mechanical energy. The efficiency is usually written as a decimal or in percentage. Example:

The efficiency of the generator is 80 percent or .8, how much current will be produced at 110 volts by a 10-h.p. engine driving the generator.

SOLUTION: 10 h.p. = 7460 watts theoretical horse power

$7460 \times .8$ = actual electrical horse power produced

= 5968 watts.

# CHAPTER III

## ALTERNATING-CURRENT CALCULATIONS

An alternating differs from a direct or continuous current in that the voltage and current periodically rise to a maximum value then fall back through zero to a maximum negative value then rise again back to zero thus repeating indefinitely. The entire period from zero through a positive value, back through zero to a negative value and then to zero again represents what

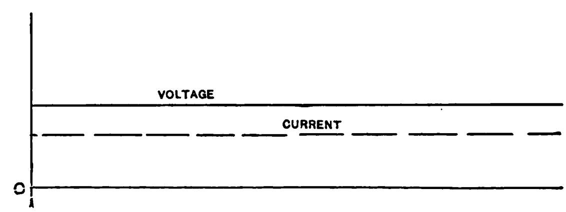


FIG. 1.—Graph of Direct or Continuous Current and Constant Voltage.

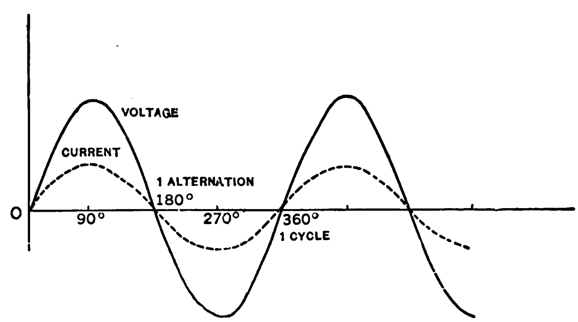


FIG. 2.—Curve of Alternating Voltage and Current in Phase.

is known as a cycle. The number of cycles occurring during one second is technically spoken of as the frequency of the system. The most usual frequency is 60 cycles per second or as a cycle is two alternations, 7200 alternations per minute, although for power purposes frequencies are in use as low as 15 cycles and some years ago a lighting frequency as high as 133 was not uncommon.

Represented graphically, a direct current would appear as in Fig. 1 when delivering current to a constant load. Alternating current would appear as in Fig. 2 under the same conditions and when the voltage and current are in phase or reach maximum values at the same instant. A curve, such as is shown in this figure, is known as a sinusoid or sine curve.

For more complete understanding of the fundamentals of alternating current, the reader is advised to consult some theoretical work on this subject.

The alternating current represented in Fig. 2 is known as a single phase but if two or more sets of waves are superimposed

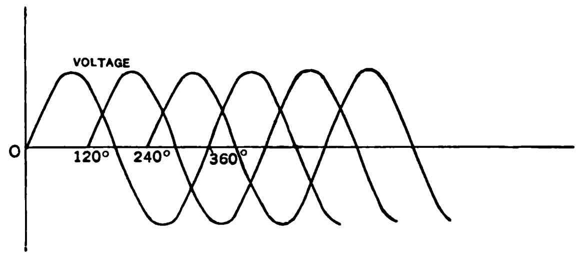


FIG. 3.—Three-Phase Voltage Curve.

the current becomes polyphase. The most usual of the polyphase currents is three phase, a voltage wave of which is represented in Fig. 3.

In referring to the voltage and current of an alternating circuit we do not mean the maximum or peak value of either but the effective or virtual values; that is a voltage or current equivalent to a direct voltage or current of the same effective values or as an example, if a certain voltage is required to burn a given lamp to a certain value and intensity, we speak of an alternating-current voltage of the same value when it burns the same lamp with the same degree of brilliancy. These values are really the square roots of the mean squares of the ordinates of the current and voltage as outlined graphically.

#### THE MODIFICATION OF OHM'S LAW

Alternating, like direct current may be calculated from Ohm's law but this law is altered by the addition of other factors

which affect an alternating circuit but not one carrying direct current. Resistance to the flow of a direct current is made up of one factor only, the resistance of the wire forming the circuit, but when we come to consider resistance to an alternating current, we find it composed of two factors, the wire resistance or $R$ that we found in direct-current calculations and in addition another form of resistance known as reactance which is caused by a counter-voltage induced by the alternating current itself.

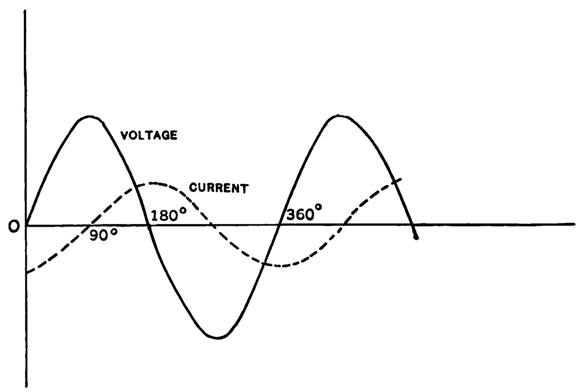


FIG. 4.—Curve of Alternating Voltage and 90° Lagging Current.

This combined effect is known as impedence and is represented by

$$\sqrt{R^2 + r^2}$$

where $r$ = reactance and $R$ = ohmic resistance.

In direct-current calculations the wattage or power of a circuit was equal to the product of volts by amperes as $I \times E$. This is also true of a single-phase alternating current when the voltage and current are in phase or when they reach a maximum and zero point at the same instant. This will always be the case in an alternating circuit when the load is composed of resistance only, such as incandescent lamps or heating devices depending on ohmic resistance for their operation. However, if the circuit contains reactance the current wave tends to lag behind the voltage wave as in Fig. 4. In this case the current is said to be lagging and the power becomes less than the volts multiplied by amperes.

The percentage of true power to apparent power is known as the power factor. Thus, the power factor or

$$PF = \frac{\text{true power}}{\text{apparent power}} \text{ or } \frac{\text{wattage}}{I \times E}$$

As every circuit contains some reactance we rarely find the power factor unity or 100 percent and if the entire load is inductive such for instance as induction motors it frequently drops to 70 percent or even to 60 percent.

The lag in degrees, when a cycle is considered as 360 degrees is usually represented by the Greek letter $\phi$ in which case the power factor may be represented by Cos $\phi$.

We find from the foregoing that the power in a single-phase circuit may be calculated as follows: $I \times E \times \text{Cos } \phi$.

In a similar manner, the power in a two-phase circuit and in a three-phase circuit:

Two-phase watts $= I \times E \times 2 \times PF$

Three-phase watts $= I \times E \times 1.73 \times PF$

### ALTERNATING CURRENT MAY BE TRANSFORMED

Alternating current, unlike direct, may easily be transformed from one voltage to another by means of static transformers and for this reason is used extensively, as the current may be generated at a low voltage and transformed to a much higher one for transmission over long distances then transformed or stepped down to a working voltage again. The reason for this may be seen readily if we consider Ohm's law, since the wattage or power $I \times E$ remains constant; if we double $E$ we divide $I$ by 2 and have the same amount of power. Now, if we take half of $I$ we may also reduce the capacity or size of our transmission wire by one-half.

From this relation, it may be seen that theoretically, we might transmit thousands of horse power over a very small wire if the voltage was sufficiently high. In actual practice an alternating current is usually generated at 2300 volts and is distributed throughout a town at this voltage. Wherever lights or power are needed, a transformer is installed reducing this

voltage to either 110 or 220 and correspondingly increasing the current.

When it is necessary to transmit alternating currents over long distances, we find that 2300 volts is not sufficiently high to obviate a large amount of drop in the wires. Therefore it is necessary to raise the voltage to a point somewhere between 13,000 and 160,000 depending on the distance to be covered and the amount of power to be transmitted. Another factor in favor of high voltage is that a given drop in potential when deducted from a low working pressure is much more serious than when taken from a higher voltage. For instance 10 volts dissipated in a 100-volt circuit is 10 percent loss while the same drop in potential in a thousand-volt circuit is only 1 percent.

From the foregoing sketch of the characteristics of an alternating current we see many factors in favor of its use and in fact we find alternating-current plants making their appearance in mining operations even in the smaller sizes. The special features of this type of plant will be considered in a subsequent article.

## CHAPTER IV

### BELL AND SIGNAL SYSTEMS

Since the earliest days of mine operation, it has been necessary to have some method of communication between those employed on the surface and the men working under ground. At first these methods were very crude, taking the form of mechanical bells or gongs, operated by a system of wires from the bottom of the shaft by a series of jerks or pulls from handles located at some convenient place. Later we find the first simple electric system, consisting of one electric bell and one push button, using either two wires, or one wire and a ground return to complete the circuit.

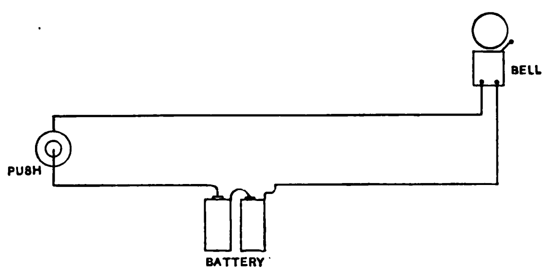

FIG. 5.—Simple Bell Circuit.

A system of this type in its simplest form is shown in Fig. 5. Communication was carried on over the wires by means of a system of signals. In some instances this being the Morse telegraph code. After some time this simple bell service was made more efficient by adding additional buttons and additional bells to the same circuit, forming a multiple system, Fig. 6. We next find the return-call method of wiring being used with a bell and push button at each end, thus, either station could signal the other without ringing the local bell, Fig. 7. This system may be used with three wires or two wires and a ground return.

All of these arrangements work satisfactorily for short dis-

tances. But as extensions were made, adding more resistance to the line and increasing the number of points at which leakage might take place, it was found necessary to employ a great number of batteries in order to force sufficient current through

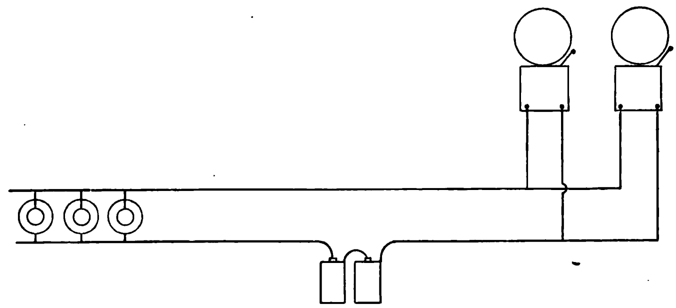

FIG. 6.—Multiple Bell Circuit. Bells may be worked in series by shorting all vibrators but one.

the line wires to adequately operate the electric bells. This difficulty was overcome by two methods, each of which, however, added a certain amount of complexity to the operating system.

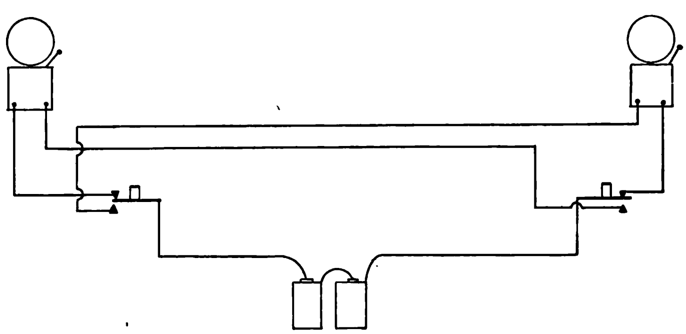

FIG. 7.—Return Call Bell System Using 3-point Pushes.

One of these methods consisted in the use of mechanical gongs which contained a heavy clock spring operating the bell, together with a very delicate release mechanism, operated by a magnet, Fig. 8, through which a weak line current was passed. The electricity, although not of sufficient force to ring the bell, could nevertheless release the mechanical spring so as to operate

the hammer striking the gong. This system operated very well if the springs were kept wound up, but frequently those in charge neglected the winding, in which case, of course, no signals could be received.

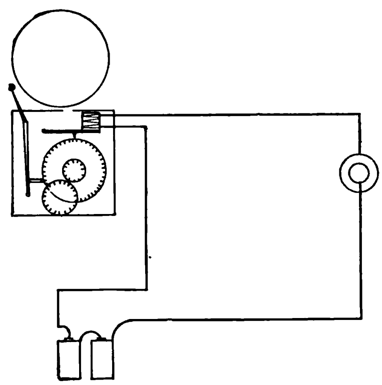

FIG. 8.—Diagram of Electrically Released Mechanically Operated Bell.

**RELAYS MAY BE INTRODUCED**

To obviate this difficulty, electric relays were introduced. The operation of this system is as follows: The weak cur-

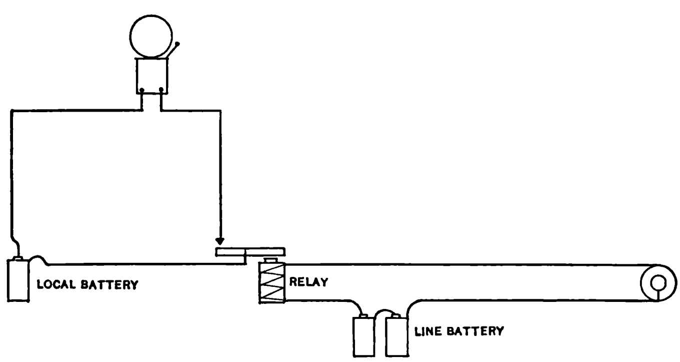


FIG. 9.—Simple Relay Bell System Open Circuit.

rent from the line is passed through a magnet coil which actuates a delicate pivoted contact which in turn opens and closes a local circuit operating an electric bell, Fig. 9. In this case one battery is required for the line and another for each local

bell section. Practically all modern systems of bell wiring used for great distances are operated on this principle and almost an infinite number of arrangements is possible and many complicated systems are in use at the present time.

One of the advantages of using relays on the line is that a closed circuit relay may be used and the bell operated only when the current passing through the line wire is interrupted. Thus, the system automatically makes known any trouble arising from a break in the line wire from bad contact or from the failure of the line battery.

Several sources of power are available for operating bell systems. The earlier signaling arrangements used wet cells almost exclusively, the leclanche type for open-circuit line work and for local bells and the gravity or blue-stone type for closed circuit line work. Owing to their convenience and adaptability dry cells are used to a large extent in many of the smaller mines, while storage cells are employed in many of the larger operations. Where alternating current is available, a low-voltage transformer can be used with marked success, especially for local bell work. These transformers require a very small amount of power which is taken directly from the line wires furnishing light. A transformer, however, cannot be used on a direct-current system, although the storage battery used on the bell system, may be charged from direct-current lighting mains, thus, avoiding the recharging and upkeep found necessary with ordinary wet cells.

Many types of wiring are used in running from one part of the mine operation to another. Each method probably having some favorable points. Perhaps the most common method is the use of bare iron telephone wire, supported on porcelain knobs, though insulated wire fastened to the woodwork by staples is sometimes employed. The chief objection to this method lies in the fact that dampness or moisture gathering on the wires allows a leakage of current and sometimes short circuits the system entirely.

Neither method is applicable if many wires are to be used as too much room is occupied by the lines and their supports. In case several wires are to be used and especially where space

is limited, as in a small shaft or tunnel, it is advisable to use a cable containing the number of wires required. In dry places, this cable may have a weatherproof braid insulation, but where dampness is prevalent, it becomes necessary to further protect the wires from moisture by an additional covering of lead.

### TELEPHONE WIRING IS EMPLOYED ABOVE GROUND

Outside the mine or on the surface the wiring methods usually used are similar to those employed in telegraph or telephone work, consisting of poles, cross arms, insulators and iron wires.

Probably the best of all known methods of communication between the different parts of the mining operation is by the use of mine telephones. If these are properly installed, and the wiring carefully done, the system is almost trouble proof. The telephones are usually enclosed together with the battery necessary for their operation in waterproof iron boxes. The cable is lead covered and waterproof throughout. Several of these phones may be used on one line and an easy method of communication established between several points in and around the mine. In some instances an inter-communicating system is used whereby any one station can call any other station without interfering with those remaining or even ringing the bell on any but the one called. This system is especially common in large mining operations where it is frequently necessary to talk between the different offices, store rooms, or supply houses.

A mine telephone, in underground work is especially useful at the time of a fall or explosion in the mine, for if any men are imprisoned in the workings they may be able to notify those on the surface of their condition and give such directions as might be of assistance toward their release.

Another system of wiring which is coming into some use is that of the automatic fire alarm. This system contemplates the use of many contact closing thermostats located at different points of the operation where danger of fire might be expected. In the event that a fire does occur, the heat communicated to

these thermostats closes an electric circuit and rings a bell used for fire purposes only.

To adequately cover the many methods of signaling used in mines would require several volumes and a brief outline only is given of the ordinary methods in use. It is to be noted, however, that much time may be saved and sometimes even life and property preserved by the use of carefully erected signal systems. To secure the installation of an outfit suitable for the use of the given mine, the services of an engineer are usually to be required, as frequently the owners are not sufficiently acquainted with the methods available to determine the most suitable or efficient installation.

### A MAP SHOULD BE MADE

After such a system is installed and thoroughly tested under working conditions, a map should be drawn, showing the methods of wiring, the location of the batteries, sources of power and the exact position of every station. This diagram should not only be kept in the office of the superintendent but should be posted up in the power house. At regular intervals an electrician should thoroughly test every part of the equipment, determining at the same time the strength of the batteries, if batteries are used, and their probable life. The man whose duty it is to inspect such a system should be required to furnish a written report, noting any defects or variations from normal operation. If defects exist, they should be remedied at once, as at any moment the satisfactory operation of bells or signals may be absolutely necessary.

# CHAPTER V

## SELECTION OF POWER PLANT EQUIPMENT

When a corporation or individual decides to open a mining operation it is taken for granted that the work will be done with the intent to make the proposition a paying investment. With this end in view careful tests are usually made and quite an amount of prospective work is done prior to regular construction. As a usual thing most of this preliminary work is done for the purpose of locating the mine shafts or drifts in the most convenient place over the seam of coal. The money thus spent is usually considered as an investment and such it is for the future economy of the mine depends to a great extent upon the location of the works relative to the coal bed.

In a similar manner, money spent in locating and designing a layout of machinery and mechanical mine accessories is usually well invested for should some error be made by which an uneconomical operation or handling of material becomes necessary, a monetary drain throughout the entire life of the plant is entailed, unless an amount should be appropriated to make the necessary changes in the existing equipment. Thus, a dollar spent in careful design may mean many times that amount in annual savings.

Considering the matter from a business standpoint, no firm can afford to build permanently without carefully mapping out the whole plan and so designing the details entering into its construction that a maximum operating economy is assured. This statement, although pertinent to the general mine layout, applies particularly to the necessary electrical appliances, since faulty design here means either expensive changes or a continual operating and upkeep expense.

The first point to be decided upon with regard to the power plant is the most economical available source of energy. This for mine operation under ordinary circumstances, will be either water power or steam. If it is found possible to make an eco-

nomical development of water power within a reasonable distance from the operation it will be well worth while to make a thorough investigation. In some instances if central station power be available, it may be a matter of economy to purchase electric current and install a small substation in place of a power plant.

Frequently a coal producer overlooks the fact that he can sell the fuel he burns to supply his own power, and ship it at a profit, feeling as he does that his fuel costs are not worth considering. Instead of thus assuming certain cost relations for parts of the plant, the entire proposed design should be rigidly investigated and questioned as to future economy in the general operating scheme.

### AN ENGINEER WILL USUALLY BE REQUIRED

This work will usually fall to the lot of some engineer and to it should be given the most painstaking attention. Few mine operators or owners have the technical training or engineering experience to work out logically the many details of a proposed installation. The field of the operator is to produce coal at the opening of the mine at a minimum cost with the equipment supplied. The province of the engineer, on the other hand, is to design the power plant and supervise the erection and installation of such machinery as may be necessary or advisable in order to secure a maximum production at a minimum operating expense.

We hear much of late regarding motion study in industrial enterprise and though this method of securing economical production is often censured there is no doubt that opportunity for realizing great gains in speed and economy by close attention to methods in handling the output exists in coal-mining work. The several parts forming the working equipment should operate as a unit, each element supplemental to the others, and working with maximum economy under the given conditions.

As the writer has previously noted a mine has an individuality, practically no two being alike as to location, general contour or natural resources. It is therefore of paramount importance that the details be carefully planned and every feature bearing

upon the future operation of the development be carefully considered before the actual work of erecting the plant begins.

The power plant is an extremely important factor in the general layout as from it is drawn electricity for haulage, for lights, and often for fans, pumps, mining machines and in fact for all power necessary in or about the mine. Again the cost of operation of the electrical equipment is continuous month by month. It may, of course, vary considerably during periods of greater or lesser activity, but means just so much toward gross running expenses. We find frequently that power plant operation costs bear a greater proportion to the entire operative expenses than any other item, labor excepted.

A mine owner or operator preparing to open a new property and invest his money as well as that of other stockholders without having a well-defined plan and the assistance of competent engineers, is laying himself and his company open to a great danger—that of buying and installing unnecessary, inadequate or unsuitable machinery. Frequently, however, the danger is in another direction, that of securing cheap or shoddy equipment. At either extreme may be found trouble and expensive operation, not only from the operating costs themselves but from upkeep and repair expenses.

Too often a manager or superintendent is induced to purchase certain machines by some smooth-tongued salesman who of course knows his own line better than any other and naturally believes it to be the best, regardless of conditions to be met or previous operating experiences with the same machine. However, it is far better for the owner if the proper equipment can be determined upon in advance regardless of what the salesmen have to say concerning their various lines of accessories.

Another danger looms up in the way of the man seeking a cheap installation, that of taking advice from an untrained or a mine-operating engineer. There are many men in charge of mining power plants who are fully competent to do their work and can secure efficient operation from a suitably designed plant, but few of the number have had the diversified training along such lines as would enable them to adequately advise regarding a new installation, or the equipment of the plant with additional

machinery made necessary by expansion. It is far preferable that an outside engineer, who by continually coming in contact with various conditions in different sections of the country becomes accustomed to reason logically and plan accurately, be called upon to design the original plans and superintend installation in all its details. The operation of an engine and generator is one thing; the wiring layout, switchboard design and line loss calculations are other matters entirely.

### THE KIND OF PRIME MOVER IS IMPORTANT

The type of power to be used, having been definitely decided upon, the next step to be determined is the particular kind of prime mover to be purchased for upon this will be based the design of the remainder of the plant. If a water wheel, shall it be an impulse wheel, vertical, horizontal or twin turbine or some other type more suitable to that particular installation? If a steam-driven plant, what kind of engine shall be used, simple, Corliss, compound or turbine and what kind of boiler or boilers shall be employed, or which of the many makes of pumps and accessories? Shall the generator be *AC* or *DC*, belted or direct connected, high or low voltage? What switchboard equipment will be necessary for this particular plant? What accessories will add to economy or satisfactory operation?

All such questions come up and must be definitely settled. The failure to consider any one factor may detract from the economy of the complete plant and it is upon the efficiency of production that we must depend for dividends. It is true that one may place almost any kind of layout in operation and may secure some sort of service from the equipment, but there might be other equipment from which it would be possible to secure a maximum efficiency and it is that plant that should be installed.

First cost, though it looms large to a promoter, is not the final test of plant expense but is merely a basis from which to start. A better method of calculating costs is to assume a certain useful life for the mine development, based on the report of mining engineers or those thoroughly acquainted with the territory and location of the coal seams and install equipment which experience and careful calculation indicate to be the most

economical over the assumed period of time as a whole. All the items of expense and of possible economy must be followed out to their conclusion and a design of the proposed plant should be drawn adapted to the given conditions. If, after careful consideration, no weak points are found in the layout, it is taken for granted that the designs are suitable and the work may be commenced.

This is an age of specialization and no man can expect to master the details of several branches of learning. Even, were it possible for him to do so, he could not gain experience in more than one pursuit at one time. Thus, the outside engineer fills a distinct and necessary place in the mining industry. It is the primary business of the mine owner to take the equipment as turned over to him and produce rapidly, economically and continually, but it falls to the engineer, electrical, mining, civil or mechanical, to carefully work out the multitudinous details to be accounted for and overcome the obstacles or mistakes that otherwise might be in evidence.

This is not written for the purpose of eulogizing the engineering profession but to call attention to the fact that any mining power plant, or any other plant for that matter, requires for its design experience, knowledge, time and careful thought, if a maximum operating economy and a minimum upkeep expense are to be obtained.

## CHAPTER VI

### DIRECT-CURRENT POWER PLANT DESIGN

In a great many of the mines, now using electricity, direct current is used exclusively both for light and power, the chief reason for this being that direct current was the first to come into general use and it is usually considered more satisfactory for haulage power. Formerly the standard voltage was 500, this voltage being economical in line copper requirements but dangerous to life and with perhaps some greater attendant fire hazard than a lower voltage.

At present, however, 250 volts is considered standard in most localities, this being the maximum allowable from the standpoint of personal injury as well as from economic considerations. Even with this voltage, which is practically double that used in distributing lighting current in city practice, the power losses in lines of even moderate length are great unless a large amount of copper is used at greatly increased cost.

The most modern practice is to use a three-wire generator, 250–125 volts, 250 volts being used for power and 125 volts to the neutral for lights. The principle advantage of the lower voltage for lighting purposes is that lamps constructed for 125 volts are cheaper, more economical and more durable than those built for 250-volt service. One generator can thus be used to furnish both light and power at the most economical voltage applicable to each.

Certain advantages obtain in the use of direct current which indicate it to be the best for small mines or those in which current is to be transmitted a short distance only. The plant equipment is less expensive, more simple in operation and requires less attendance than that of any other type. Motors operated for power on direct currents have high starting torque, are easily adapted to various speeds and can safely withstand comparatively rough usage and heavy overload.

Briefly we shall outline the requirements of a modern direct-

current installation, considering the equipment by composite items.

The prime mover of any plant is the basis upon which the entire installation is built and upon which the ultimate efficiency of the plant may depend. For mine work, it may be a steam engine, steam turbine, water wheel or even a gas engine, and so many factors enter into the determination of a suitable and efficient power that a separate chapter will be devoted to the prime movers and generators.

The source of all electricity used for power and lighting work is the generator or, as it is frequently called, the dynamo, and upon it the entire plant must rely for continuous and satisfactory operation. No cheapening must be evidenced at this point and first cost must not be made paramount to service. A few dollars saved in the original installation may mean many dollars spent for repairs and upkeep throughout the entire life of the mine.

In very small installations a moderate-speed, belted machine is quite satisfactory and cheaper than one direct connected to the prime mover because the direct-connected generator is necessarily a slow-speed machine; but when a plant is of considerable size the latter type is most strongly recommended as being more sturdy and more dependable under heavy overloads. If power alone is desired for haulage, motors and fans, a two-wire system may be used, but if lighting circuits of any size are to be run from the power house a three-wire generator will be more economical as has been mentioned previously.

The instruments required on a modern direct-current switchboard to some extent depend upon the size of the installation, but it is far more satisfactory to secure a fully equipped board than to attempt to operate a plant successfully which is but halfway equipped. Primarily we need a two-pole circuit breaker or fused main-line switch. The circuit breaker, though higher in first cost, obviates the necessity of carrying in stock an extra supply of fuses and is usually more economical considered over the whole time of amortization. See Fig. 10.

The haulage motor, or trolley line, should be on a separate single-pole breaker and the lighting feeders on still another

two-wire breaker or fused switches. On the lighting service, the neutral at no time should be fused or run through a breaker, as failure of the neutral circuit would create a serious state of unbalance in the lighting load and probably burn out many lamps. An ammeter, preferably with a shunt, voltmeter, ground detector, pilot light and field rheostat should be mounted on the board.

Suitable lightning arresters must be placed just outside of

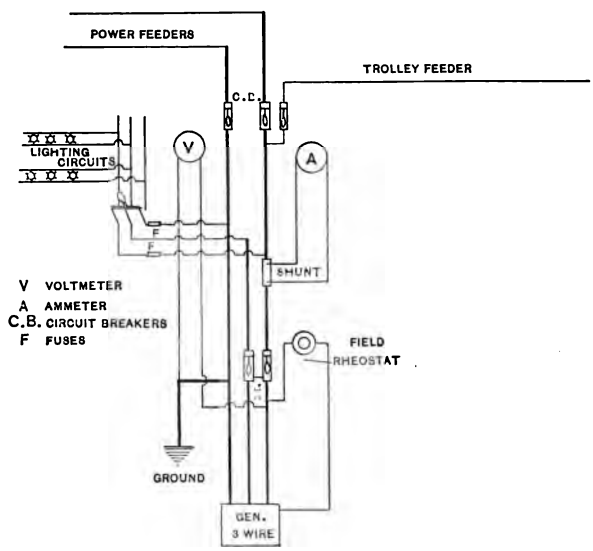


FIG. 10.—Simplified Diagram of 3-Wire D. C. Switchboard.

the building and connected to an efficient, permanent ground. The framework of the board, the frame of the generator and the negative lead should be connected with the same ground. The switchboard panel should be of marble or of slate on an angle iron or pipe framework. Every part of the support and accessories to the board should be fireproof.

As a check upon operating costs per unit output an integrating or recording wattmeter should be placed on the board and a daily log kept by the engineer in charge of the plant of operating characteristics and daily output in kilowatt hours. If two or more generators are being installed they should each have a panel in the board and be arranged to operate in parallel if

necessary by means of equalizing switches on pedestals at the machines. The lighting feeders, if several in number, may be connected to the distributing panel and from this point may be run the branch circuit necessary to light adequately the generating room and plant building.

The entire plant should be well lighted with consideration for the work to be done and the welfare of those employees who work at night. The wiring should be installed in a neat

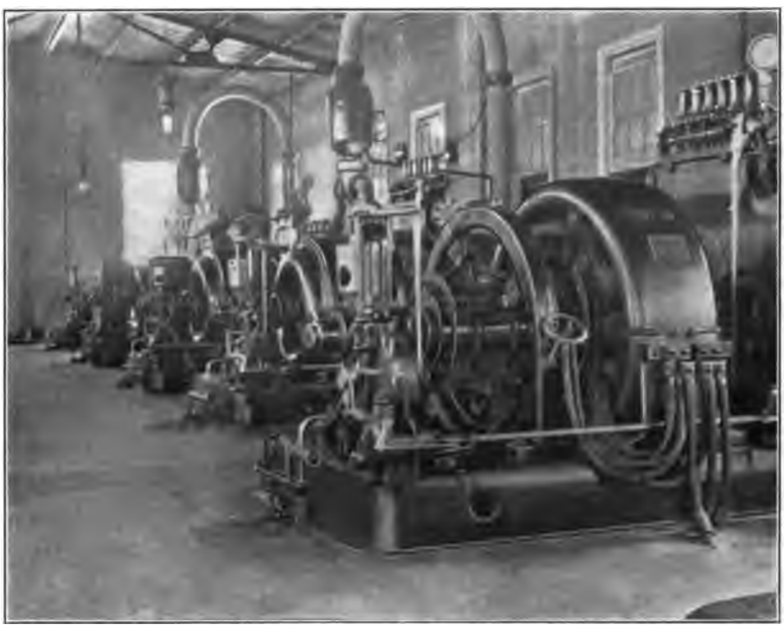

FIG. 11.—Steam Turbine Mining Power Plant.

and secure manner with careful attention to details upon which the safety of the wiring installation depends.

Where possible, it is preferable to run generator leads to the switchboard in underground conduit, as it not only adds to the appearance of neatness but prevents the possibility of injury to the cable. The grounding of the negative buses for the trolley system should be done outside of the building and the same ground may be used for all purposes if properly made.

All bus bars and leads on the switchboard should be of suffi-

cient carrying capacity securely put up and all points sweated permanently. It will be economy, in the long run, to install the entire plant layout in strict conformity with the National Electric Code Standard. Too often we find in a mining plant evidences of carelessness and a slipshod method of wiring which detracts from the appearance, adds to the fire hazard and frequently causes the plant to be uneconomical in operation and upkeep.

The first cost of plant equipment is usually sufficient to

FIG. 12.—Turbines and Reciprocating Engines in a Mining Power Plant.

justify the erection of a solidly built roomy building as nearly fireproof as possible and having adequate floor space for all the machinery and accessories without crowding. See Figs. 11 and 12. All foundations should be well built and of sufficient size to obviate undue vibration. A concrete floor is frequently found advisable and if such is the case in a particular plant, a small board platform or rubber mat should be placed at the front of the switchboard on which the attendant may stand while operating the switches.

Just outside of the building, as near the board as possible, should be erected a distributing rack or pole to take the feeder wires as run from the back of the switchboard and distribute to the different points needed. All this power house wiring should be securely placed upon porcelain supports and well insulated throughout. If the engineer has a diversity of duties,

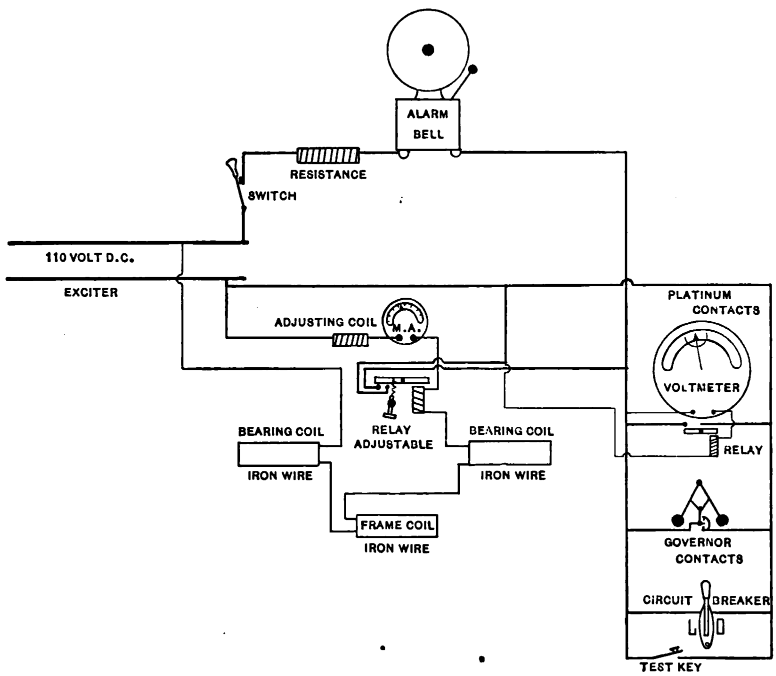


FIG. 13.—Power House Alarm System.

which require him to be away from the generating room any considerable amount of time, it is best to install an engine room alarm equipment which sounds a gong if the circuit breaker trips or the generator or bearings overheat. See Fig. 13.

In this particular, we usually find a lamentable lack of care in design and erection. If a plant owner finds it necessary to build lines at all, it would pay many times over to build them right and thus secure immunity from future repair bills on outside equipment.

A plan should be made showing the length and probable load

upon every line of wire, taking into account the generator capacity and the future needs of the plant. A maximum allowable voltage drop should be decided upon and this used in calculating the size of all the feeders and branch circuits. If the trolley lines are long, it may be a matter of economy to run separate feeders into the mine so that taps to the trolley wires may be made at frequent intervals.

All cable and trolley work in the mine should be done with extra precaution having in mind upkeep, danger of accidents, fire hazard and economical operation. Long spans of wire should be avoided. All poles well anchored and guyed where necessary cross arms firmly attached and well braced and the whole installation carried out in a neat workmanlike manner. These extra precautions may seem unnecessary but they mean economical, continuous and satisfactory operation, small repair bills, and practically no upkeep expense. No one can expect machinery and wiring thrown together in a haphazard way to give satisfaction and stand up under hard mine service.

Before any work whatever is done or material ordered, have a definite plan made of the entire layout, showing sizes, calculated losses, estimated operating costs and other items that might go toward assisting those installing and later those operating the plant. Assume the proper depreciation charges and estimate gross annual operating expenses. If the plans are satisfactory after having been carefully checked, and every phase of the proposed installation considered, buy the material and install properly. After complete installation of the equipment, have it thoroughly tested annually in order to keep output at the maximum and operating costs at a minimum. By following this course small misadjustments and troubles is that might become serious may be corrected in their incipiency and the entire plant kept in excellent condition.

## CHAPTER VII

### ALTERNATING-CURRENT POWER PLANT DESIGN

When we come to the consideration of alternating-current power plants we find many features differring from those met with in direct-current practice. While the use of the commutator limits to some extent the voltage at which one may generate direct current, we are not restrained as to voltage limits in alternating-current work by this feature for the alternating generator has no commutator.

If the current for power and light is to be transmitted some distance, it is usual to use 2300 volts on the distributing network and reduce this voltage to 110 for lights and 220 for power at the points of application by the use of transformers. Now, we could easily generate the alternating current at 220 volts raising this by means of transformers to 1100, 2300 or even higher for distribution. However, the features of design obtaining in an alternating generator make it as easy to generate 2300 volts as at a lower potential. Owing to this fact, a 2300-volt generator is usually installed, the current flowing directly from the machine through the switchboard and out to the primary line.

As to the type of current suitable for use in a mine installation, we may use either a single-phase or polyphase system; however, as the single-phase system is not particularly suitable for operating motors it is usually better to install a three-phase system. The chief difference from the construction standpoint being in the fact that while two wires only are required for the single-phase system, three are necessary in three-phase work.

The same remarks regarding methods of connection, prime movers and speed apply to alternating-current generators as to direct.

Practically no modern alternators are self exciting, that is, the current required to magnetize the field coils must be furnished by a small auxiliary direct-current machine, usually operating at 110 or 220 volts. The current from this generator

flowing through the rapidly revolving field of the alternator induces the alternating current which is used for light and power. As the voltage of an alternating plant is usually high, it is necessary to exercise especial care in the installation of the plant and the insulation of those parts carrying current.

The modern alternating-current generator switchboard should contain as a minimum the following instruments: (1) An oil switch in the generator leads with a trip mechanism operated by overload relays. This switch takes the place of the main circuit breaker and not only furnishes the means for disconnecting the generator from the line but also operates in case of an overload or short circuit. (2) To measure the current generating by a three-phase alternator we need either three ammeters, one for each line, or one ammeter with a switch arranged so that the current from any of the lines may be sent through the instrument. Probably the installation of three ammeters is more satisfactory as at any moment the condition of load or balance on all three phases may be determined at a glance. (3) It is not usual to allow the entire current to pass through the ammeter but to use a transformer furnishing to instruments a definite proportion of the main current. These same transformers may be used to furnish the current sent through the overload relays and even a wattmeter may be further added. (4) One voltmeter is necessary which is connected to voltmeter receptacle and plug by means of which the voltage on either of the three phases may be read. (5) As is the case with the ammeters, it is usual to use a transformer (called a potential transformer) on the voltmeter which is adjusted to furnish a definite proportion of the voltage on the main line to the instrument. Both ammeters and voltmeters are usually calibrated to indicate the current and voltage on the main line irrespective of the ratio used in transforming.

If more than one generator is to be used in the power house, each should have an individual panel in the switchboard and each panel should be equipped with a synchronizing receptacle by means of which the machines may be connected together electrically and made to operate in synchronism or in phase. In the case of a large installation the exciters should each have

a switchboard similar to that employed in a direct-current plant and equipped with the same instruments.

If the plant is a small one, in which one alternator only is used, we may dispense with the exciter panel and place the instruments necessary for its operation on the main board. See

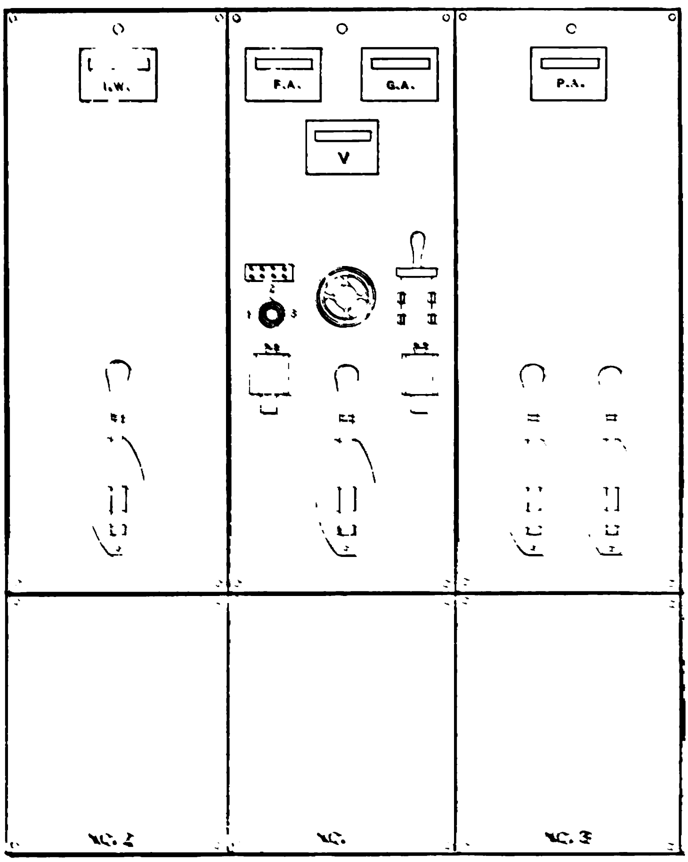


Fig. [illegible]. Alternating Current Switchboard. Three-Feeder Circuits.

Fig. [illegible]. These instruments would consist of a main exciter or field switch, as it is called, equipped with a discharge contact and resistance to destroy the arc formed by the sudden breaking of the current in the large generator field. A direct-current ammeter should also be furnished for use on the exciter. Two rheostats are usually used, one for controlling the voltage of

the exciter by varying the current in its field and one for controlling the current in the alternator field.

Pilot lights should be used, one on the exciter and one on the main generator to indicate approximate voltage before throwing the switches. The voltage on the one placed on the alternator being reduced by means of a small potential transformer. A ground detector also should be located on the switchboard to be used in determining if any of the main lines are grounded through contact with some uninsulated material.

The switchboard, as in the case of that used in direct-current work, should be made of fireproof material, such as marble or

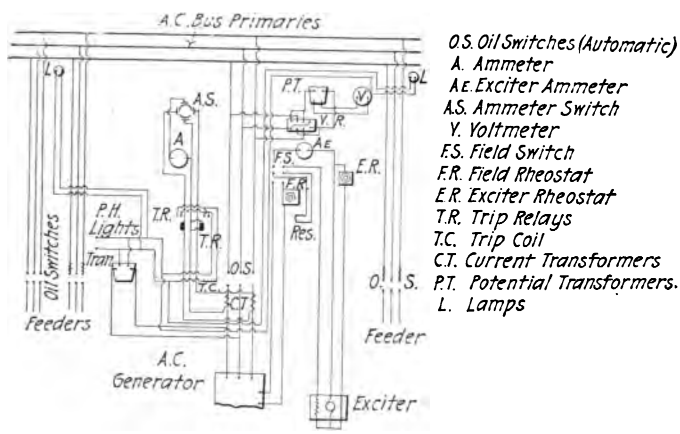


FIG. 15.—Simplified Wiring Diagram of A. C. Switchboard. Front View shown in Fig. 14.

slate, thoroughly supported on a substantial framework and of ample size. The frame of the board and the frame of the generator, as well as the casing covering the instruments, should be grounded to preclude the possibility of any one being shocked or killed from contact with these parts. It is customary to install a small lighting transformer and distributing board somewhere near the main switchboard to furnish the lights needed in and around the power house. (See Fig. 15, wiring diagram.)

All interior wiring carrying high voltage should be well insulated and placed on glass or porcelain supports well separated

from each other and from the surface wired over. If the main leads from the generator are carried through a conduit under the floor, the wire should be especially designed for use with high voltage and be moisture proof. The exciter wiring, being of low potential, may be installed in a similar manner to that of any low-voltage plant.

Just outside of the power house the high-voltage lightning arrestors should be placed on the primary lines and between the arrestors and the switchboard an air-core choke coil is placed on each lead to keep lightning discharges from entering the plant.

In regard to the outside line work, it is necessary to use more care in the erection and installation of alternating-current wires than direct, on account of the higher voltage. At least two cross-arms must be used on each pole; the top arm to be used for the 2300 volts primaries and the lower arm for the secondaries carrying the low-voltage current supplied by the transformers.

The transformers may be placed on the primary line at any point where light and power are to be used; or all the transformers may be connected together to the secondaries so that in case of overload at any one point the transformers at other places on the line will assist in carrying the load. In the case of small motors, it is customary to use three-phase, 220-volt current furnished by a three-phase transformer or three single-phase transformers connected in Y or Δ. However, in the case of large motors, the primary 2300-volt current is often used direct without the use of any transformers.

Although alternating current is used to some extent for mine haulage and for hoisting work, it is frequently found necessary to install rotary converters or motor generator sets to change the alternating into direct current at the point of power application. The direct current is then employed in suitable motors for hoisting and haulage. The chief point in favor of the direct-current motor is its large capacity for overload and speed-varying characteristics.

Returning to the further consideration of power house design the generator room should be of ample size. The machinery foundations heavy and the building well lighted. The exciter

should be of adequate capacity to furnish the alternator with sufficient current even under heavy overload and the alternator should be of sufficient size to carry all the designed load without reaching its maximum.

Carrying this line of argument still further, the prime mover should be of ample size to pull both the generator and exciter if these were fully loaded without appreciably slackening speed. It is well known that a plant designed upon a liberal basis is more easily kept in first-class operating condition, is less liable to mishaps or breakage and is more economical in operation than one of barely sufficient size.

The makers usually guarantee their machines to carry 25 percent overload but it is not well to depend on this 25 percent in the initial design of the installation. A modern power plant should have all the instruments necessary for determining the amount of power generated and furnished, the efficiency of the machinery and the operating expense per kilowatt or per horse-power hour. A record of all the items going to make up these costs should be kept so that the efficiency of the plant as a whole may be maintained continually at a high standard.

The same considerations regarding the alarm system apply to the alternating plant as to the direct and it is usually a matter of economy to install such equipment. A scheme of this kind allows the engineer more time to look after the other details of his plant, check up the operating costs and keep the equipment up to high standard. In many installations where no alarm system is used, the engineer must of necessity continually watch his generator and switchboard when he might be more profitably employed on other work.

Any coal company contemplating the installation of a power plant of any type without securing the services of a competent designing engineer is almost sure to make a serious mistake, and incur unwarranted expense or serious trouble from the use of inferior or inadequate equipment. Many details of the installation of an alternating-current installation require much study, and considerable calculation is sometimes necessary to determine the most economical methods to be used in a given plant.

## CHAPTER VIII

### PRIME MOVERS AND GENERATORS

Perhaps the most important part of any plant used for mine operation is the prime mover or source of power by which the electric generating equipment is driven. The chief reason for this is the fact that this part of the equipment varies more widely in first cost, operating expense and upkeep than any other part of the entire plant. In considering the generating equipment, we find that the efficiencies of all standard machines is high, ranging from 85 to 90 percent of the power expended on the generator shaft. Moreover, if properly installed, a generator is not liable to rapid depreciation or inherent accidents, nor does the efficiency diminish with the age of the machine.

If we examine the steam engine, in the light of generator-operating characteristics, we note that it is a very inefficient machine and that this inefficiency increases rapidly with the age of the engine. We cannot, however, consider the engine alone from a practical standpoint in determining the prime-mover efficiency of a steam power plant for the very evident reason that the boiler or boilers play an important part in regard to the operation of the engine.

Engines are classified into several distinct types, each of which may have some favorable points offsetting which are certain inimical features applicable to each type of machine. The simple slide-valve engine is perhaps the most common, it being cheaper in first cost but far more inefficient than later and more costly types.

Even the slide-valve engine is found in two varieties, the high-speed or automatic cut-off engine which is perhaps the more modern type and the slow-speed or throttling engine. This latter form is almost obsolete, owing to its lack of regulation and its inefficient consumption of steam. For small installations, say 100 h.p., the high-speed automatic is very satisfactory, but when it becomes necessary to install a larger unit, it is usually advisable to use a more efficient type of engine.

In the larger types we have the Corliss, condensing and compound. The chief value of the Corliss engine lies in the type of valve gear used. In this machine the valves for inlet and exhaust may be adjusted separately and individually so that the point of admission and release may be set at the most economical operating points for a given set of conditions, while in the slide-valve engine the same valve unit is used for both inlet and exhaust and therefore is not subject to adjustments.

Within recent years, engines of the four-valve type have been brought out differing to some extent from the Corliss system. High economy is claimed for some of these machines which are usually of the non-releasing type. Although some simple Corliss engines are in use, it is usual to find them run condensing as by so doing we secure some 10 or 12 lb. more working pressure on the cylinder heads.

A step further in this direction leads us to the compound condensing Corliss engine in which type there are two cylinders. The steam is admitted first to the high-pressure cylinder and the exhaust from this cylinder used in the larger low-pressure cylinder after which it is exhausted to the condenser.

With an engine of this last-named type we may secure an efficiency approximately three times as great as with the simple slide-valve throttling engine. Another point in favor of the compound condensing unit is that the efficiency of this type of machine holds up well throughout the life of the plant.

### THE STEAM TURBINE

Another type of prime mover which has come into prominence within the last 10 years is the steam turbine, either used alone or in conjunction with a Corliss engine. The turbine is noted for its high speed and for its ability to utilize steam containing a high degree of superheat, the use of which cuts down condensation losses and adds to the overall efficiency. Owing to the high speed, it is usual to find the turbine used to drive an alternating-current generator, the direct-current generator not being well adapted to such high speed on account of commutator troubles. The efficiency of the ordinary steam turbine,

when used alone, is perhaps not quite so high as that of the compound Corliss condensing engine, but when designed for low pressure and used on the exhaust from a Corliss machine, a marked increase in economy is possible, considering both engine and turbine as a single unit.

So many factors enter into the proper selection and installation of steam engines and their accessories that each individual case must be worked out separately after all the factors governing the plant operation have been determined. The probable life of the plant must be assumed from past experience with similar installation and the cost of several different types of equipment must be estimated.

After this the economy and cost of operation of the differing types must be determined. With this data clearly expressed, a balance must be worked out between the efficiency desired and the initial cost. No detail should be left out that would go toward adding to the overall efficiency; such, for instance, as properly covering the steam pipes, the use of superheaters and economizers, the installation of feed-water heaters and the proper utilization of as much of the heat produced by the burning coal as is possible.

#### BOILER EFFICIENCY IS IMPORTANT

The efficiency of the steam plant depends largely on the boiler also, since we may use a good engine on a poor boiler or *vice-versa* and secure very unfavorable results. The number of types of boilers and boiler accessories is almost unlimited and it is really difficult to determine just what type to use under certain conditions. Formerly practically all boilers of any size were placed in a brick setting, but within recent years several manufacturers have brought out types of boiler which are self-contained and require little or no brickwork. These boilers have the advantage in that there are no cracks in the setting or furnace by means of which air can leak through and thus decrease combustion efficiency.

As a usual thing, a feed-water heater should be used with a boiler of any size so that the water may be pumped to the steam generator at as high a temperature as possible, thus securing

a gain in efficiency and preventing damage to the boiler plates by the sudden admission of cold water. As the gases usually leave the boiler tubes at a comparatively high temperature, a considerable saving may be effected by passing these flue gases through an economizer before admission to the stack. The draft in the furnace may depend either on the stack or on a system of fans or blowers. Each of these methods has certain advantages and must be determined upon during the initial design of the boiler plant layout.

Two methods of firing boilers are in common use, hand firing and mechanical stoking. For small plants where a careful fireman is employed, the hand method is very efficient, but larger plants and those in which it is difficult to secure competent firemen are largely employing mechanical means to force the coal onto the furnace grate.

Two factors of saving are introduced by the use of mechanical stokers: a saving in labor cost if the plant be of some size and the obviation of the personal element in methods of stokng. The mechanical stoker, if properly installed, fires continuously and uniformly, while it is well known that in hand-fired plants one man may use 25 percent more coal than another without increasing the steam output.

Another saving accrues from the fact that when using a mechanical stoker it is rarely necessary to open the furnace doors, whereas with hand firing this is an absolute necessity and at every time of fuel replenishment large quantities of cold air are admitted to the furnace, thus to some extent cooling the boiler tubes.

A fact worthy of the closest attention is the saving made possible by the use of adequate instruments, for the proper determination of the operating characteristics of both boilers and engines when properly manipulated by a fireman or engineer, having in mind the good of his employer and the necessity for economical operation. Among such instruments may be mentioned draft gages, steam flow meters, water meters, coal-weighing apparatus, carbon-dioxide recorders, feed-water thermometers, besides the regular equipment of any steam plant, such as steam and vacuum gages and other necessities. If

these instruments are properly used, and the engineer is forced to keep a systematic record of the operation of his plant, great gains and economy are possible.

Some may say, "What is the necessity of so closely guarding economy in the power plant of a mining operation where coal is plentiful?" The answer to this point, which is often raised, is that the coal which is burned in the boiler to produce power for mining operations is worth just as much as the coal that is placed on the car for shipment and if it is worth while to mine the coal, in order to ship it, it is certainly worth while to effect any saving possible by reasonable means in the fuel consumption of the plant. Many mine owners forget that although the first cost of an efficient plant is higher than that of one inferior, the saving from this efficient operation extends over the entire life of the mine and may reach such an amount as would pay for the plant several times over. Another point in favor of the more extensive plant than is usually installed is that such a plant is less liable to breakdown and expensive upkeep.

### WATER POWER IS CHEAP AND DEPENDABLE

A power which was rarely used in mine work until recently but which is coming to the front on account of its continuity of service and cheapness, is water. At the present time, we find many mines served by water power solely and this frequently over long transmission lines. It sometimes happens that a water power plant can be installed more cheaply than a steam plant of the same size although this is rarely the case. In any event, however, the operating cost of the water power plant, if within a reasonable distance from the mine, will be considerably less than that of a steam plant.

Many types of water wheels are in use, each best fitted for a particular condition to be met and many different arrangements of connection between a water wheel and a generator are in use. The most common type of hydro-electric plant consists of a reaction turbine water wheel, direct connected or geared to an alternating-current generator. We frequently find, however, a generator belted to a jack shaft, operated by bevel gears from the wheel shaft. The use of direct-current genera-

tors in a water power plant is not at all common, owing to the fact that the power plant is usually located some distance from the mine operation, thus necessitating a high voltage transmission line to cut down transmission losses and decrease the size of wire necessary.

In location, design and installation of a hydro-electric plant for use in operating a mine, we are confronted by the same problems which have to be met in the steam plant. That is, we must consider all the peculiarities of the power site and of the conditions to be met in the operation of the plant. Many factors must be considered in the initial design and much preliminary calculation done before a definite layout can be determined.

Many mine owners have recently found that several mines may be adequately served from one water power plant with a marked saving to all concerned. In some instances, when a good water power site can be secured, it is advisable for the mine owners to form a stock company among themselves and erect such a plant, after which, each purchases sufficient power for his own use from this central plant.

Many mines can be served from one plant more efficiently than one mine, because the surges or load peaks come at different times on the different plants, thus smoothing out the power plant load. Again it takes very little more labor to operate a large hydro-electric plant serving several mines than a plant operating only one. When such an arrangement is possible the owners of the plant can employ more competent electricians and furnish better service throughout.

It is possible also to use one crew of repair men and trouble shooters for all the mines, thus obviating the necessity of each mine running its own repair shop and employing a crew of men which are idle a large part of their time.

Great possibilities are open to mine owners along these lines as the developments during the next few years will no doubt show. But those reaping the greatest gains will be those who soonest put into effect systems of this kind.

# CHAPTER IX

## MOTORS AND HAULAGE EQUIPMENT

A motor is essentially a machine for changing electrical energy into mechanical power and is used at points where this power is needed for driving machinery. Two classes of motors are in common use, those used on alternating current, and those used on direct. Each of these classes is then further subdivided into a great many types, each type having operating characteristics peculiar to itself and each suitable to certain kinds of work.

Considering the direct-current motor first, we find three types in use, the series, shunt and compound wound. The chief characteristic of the series motor are that it has a large starting torque, is easily controlled in speed by resistances and varies in speed almost in direct proportion to the load. For these reasons, series motors are nearly aways used on mine locomotives, hoists and other machinery operating at various speeds.

The shunt motor operates at very nearly the constant speed for which it is wound. The speed, however, drops to some extent upon the application of a heavy load but usually only a small percentage of the normal rating. Shunt motors are suitable for the operation of many types of machines, fans, pumps and other mechanical equipment not requiring a great variation in speed.

Compound motors, especially when equipped with interpoles are used probably more than any other kind. The characteristics of this motor lie between those of the series and the shunt-wound machines. They have the advantage over the shunt motor in that they start with a higher torque and are capable of assuming greater overloads. Such motors are suitable for operating practically every kind of machinery except that which requires great variations in speed, although some types of variable speed compound motors are on the market.

The real difference in these three types of motors is found in the field windings. In the series motor, the entire line current

passes through the field and then through the armature, thus, when heavily loaded, the field is much stronger than when lightly loaded, the strength of the field varying in proportion to the line current. See Fig. 16. In the shunt motor, the field takes a definite amount of current continually, this amount depending not on the motor load but on the line voltage. Since

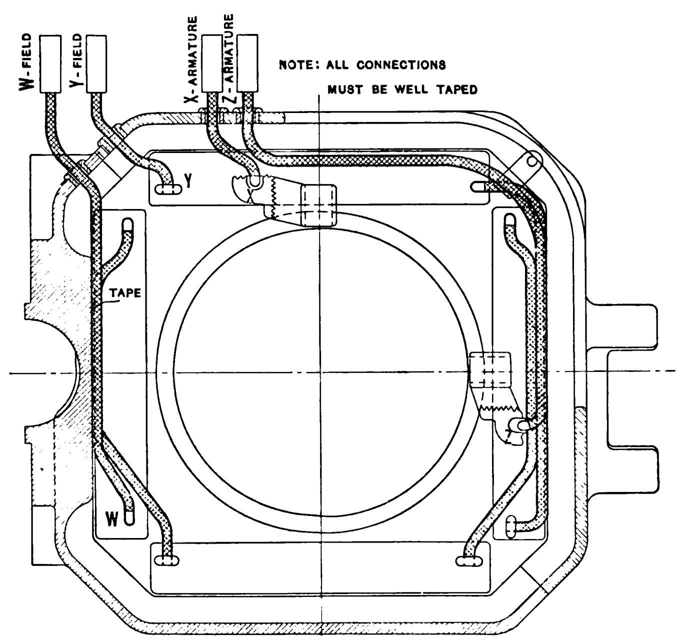


FIG. 16.—Series Motor Connections.

the line voltage drops slightly, when the motor is heavily loaded, the field is to some extent weakened.

As a constant field tends to produce a constant speed, we secure a close regulation. If we weaken the field of a motor, the speed increases and if we strengthen it the speed decreases. Thus a series motor without a load may run away and destroy the winding since the field is very weak when the motor is doing no work. The compound motor has both a series and shunt field and thus partakes of the nature of both of the preceding types.

**INTERPOLES ARE NOW FREQUENTLY USED**

Within the last few years an additional winding on the field of a motor has come into extensive use. This is called the interpole winding and is placed on auxiliary poles located midway between the main poles. See Fig. 17. The chief use of these additional poles is in reducing the sparking at the commutator.

In alternating-current motor practice, we have two general

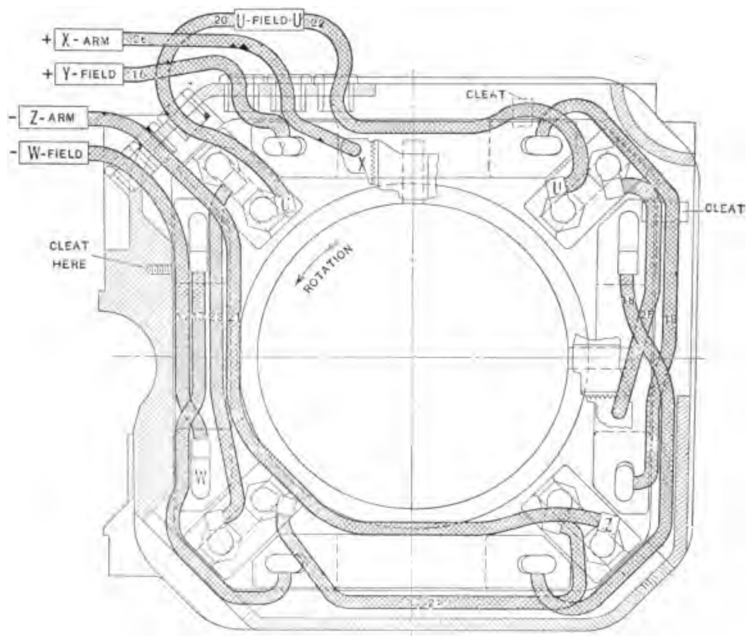


FIG. 17.—Interpole Motor Connections.

classes, single phase and polyphase. Although single-phase motors are used to some extent the operating characteristics are not very satisfactory, owing to the difficulty of bringing the machine up to speed. The polyphase motor, however, and especially the three phase is quite satisfactory in operation and rugged in construction. Three general types of the polyphase motor are in use, the squirrel cage induction motor, wound rotor induction motor and synchronous motor.

The squirrel cage motor is similar in operating characteristics

to the shunt motor but has the advantage that no open contacts, brushes, or commutator are used. Taking everything into consideration, this is probably the most rugged motor now used, the chief disadvantage being that the speed is not easily varied except by a rather complicated method of changing the number of poles in the stator.

The wound rotor motor is used almost exclusively where speed variations are necessary. As regularly equipped, a speed variation of 50 percent is possible by introducing a variable resistance in the rotor circuit. This motor, however, has open contacts as the windings on the rotor are energized through three sets of brushes running on slip-rings.

The synchronous motor is rarely used except in large units, as the starting torque is very low without a special induction winding for starting duty. When the machine is brought up to speed, however, it keeps in exact step with the generator supplying the current. Probably the greatest use for these motors is in substation work, where a synchronous motor is direct connected with a continuous current generator. Synchronous motors are often used for power factor correction, since from the nature of the machine, when running with overexcited fields, it produces a leading current and thus counteracts the lagging current found on a supply system loaded with induction motors.

### DIRECT CONNECTION MAY OFTEN BE MADE

In the use of electric motors for mine service in connection with the various machines, found in such an operation, the characteristics of both alternating- and direct-current motors are such that in many cases they can be direct-connected or geared to the driving shaft, in this manner eliminating to a large extent friction losses and the first cost and upkeep of belts and counter-shafts. It is also possible to use a motor with each individual machine obviating almost entirely line shafting and hangers.

This use of individual drive tends to increase the efficiency of a mining operation because no machines or shafts need be run except those actually in use. In the older methods, when operating by the use of the steam engine the greater portion of

shafting and belting was running continuously, thus increasing friction losses by an appreciable amount. In operating crushers, the momentum of the rotating part in a motor adds a flywheel effect which is perhaps of some advantage over a belted connecton from a line shaft.

Practically all motors for use on both direct and alternating current are capable of carrying extremely heavy momentary overloads and 25 percent overload continuously without overheating. Ordinarily, the temperature rating of motors is considered 40 deg. C. (72 deg. F.) above the surrounding air when operating fully loaded and 55 deg. C. (99 deg. F.) under 25 percent overload.

Another advantage obtained in the use of individual motors is the ease with which power measurements may be made, for since each motor and the machine which it is driving forms a unit, instruments may be connected temporarily in the lines and actual power measurements of the machine load taken. This is of great advantage in that a machine may be worked at its full rated output and at maximum economy. This measurement also forms a check upon the operation of the motor, showing when it is overloaded or in need of repairs.

Still another advantage is in regard to peaks or overloads occurring at different points in the plant. The peaks rarely ever come on several machines at the same time, thus, the electrical wiring system is in a sense distributive, supplying excess current immediately to those points which are overloaded. Any one of these motor units may be shut down temporarily for adjustments or repairs or even moved to another location with absolutely negligable effects on the remainder of the system.

The ease of connection, flexibility and lightness in weight of electrical motors renders possible the use of portable machines and changes as to location or arrangement of machines in use may be made without interfering with the operation of the remainder of the equipment.

#### THERE IS A TENDENCY TOWARD STANDARDIZATION

The tendency in electrical power applications to the use of coal mines is toward standardization either in the use of direct

current throughout or by using synchronous or induction motors for work on the surface and direct current supplied by rotary converters or motor generator sets for mine haulage.

In the use of a suitable power for mine haulage, the advantages and superiority of electric locomotives is generally conceded. This is due to the fact that an electric locomotive may be small in size, compact, simple of control, highly efficient and of great mechanical strength. Although compressed-air locomotives have been used to some extent, their efficiency is very low and at best they are cumbersome and require frequent charging from air lines laid in the mines.

Steam locomotives are almost entirely ruled out of mine work, owing to the large space required for their use and a smoke and fire hazard. Gasoline locomotives, too, have been used with some success but are sometimes difficult to start, not able to withstand heavy overloads, expensive to maintain and have a lower tractive effort than an electric locomotive of corresponding size.

The life of a trolley type electric locomotive is long. One is known which has been in use almost constantly for twenty-two years. No doubt any other type of haulage motor would have been in the scrap pile after ten years use.

Electric locomotives secure current for their operation by two methods. In one, the most commonly used, a trolley wire is carried on insulating supports into the mine above and alongside of the track. This forms one line of the electric circuit while the rails upon which the locomotive runs form the other. Another type of locomotive secures current from a storage battery carried on the frame of the machine which is charged at regular intervals from a direct-current supply.

### THERE ARE THREE GENERAL TYPES OF TROLLEY LOCOMOTIVES

Three general forms of trolley type electric locomotives are now in use, the straight haulage, cable reel or gathering, and a combination or crab type. The standard weight ranges from two to thirty tons and some of the smaller sizes do not exceed 28 in. in total height. The straight haulage type is of un-

doubted value in hauling cars to the shaft or tipple in a mine having reasonably long haulage. This type is in use in practically all mines where electric service is available. For this service, the use of mules has practically been discarded, since one locomotive can deliver considerably more tonnage than several animals, can move faster, enter lower tunnels and if necessary operate continuously.

Gathering locomotives are very similar to the straight haulage machines but in addition have a rotating reel operated by a

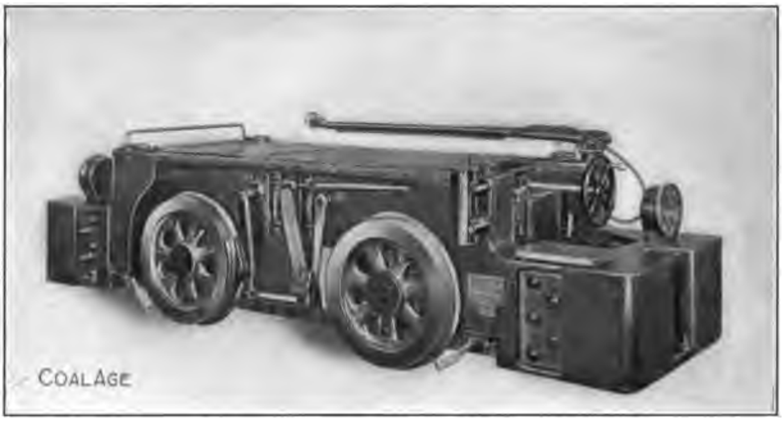


FIG. 18.—General Electric Straight Haulage Locomotive.

small auxiliary motor which carries a long length of electric cable so that a locomotive of this type is able to go into cross entries where there is no trolley line and be fed by current supplied through this cable which it reels off on the ground when leaving the trolley line and winds up as it returns to the main track. The operation of this reel is entirely automatic, so that the driver may give his entire attention to the operation of the main or driving motor.

The crab type locomotive is similar to the haulage machine but with the addition of a hoisting drum operated by a strong compact series motor. A locomotive of this type may be blocked in an entry and by means of the hoist rope draw the loaded cars up the slopes and deliver them on the main haulage track. A few locomotives have been equipped with both the

Fig. 19.—General Electric Gathering Locomotive.

hoisting drum and cable reel so that they may be used for practically every service required in haulage operation. Locomotives in two of these types, as built by the General Electric Co., are shown in Figs. 18 and 19.

In the operation of mines located a considerable distance from the tipple or breaker, it is possible to advantageously use much larger locomotives than those just mentioned. Since compactness is not required of these machines they may be of larger size and heavier framework.

Some makers use one motor only on a locomotive connected to both axles by means of some form of gearing, others use separate motors connected to each axle. As a usual thing, the controller and all the more delicate parts, if any part of a mine locomotive may be called delicate, are thoroughly housed in, so that damage from falling rock, derailment or ordinary accicents is almost impossible. The controller is usually of the drum type which consists of a series of contacts turned against a corresponding series of fingers placed in a steel case.

Some haulage motors are equipped with a heavy steel pinion placed on the axle midway between the driving wheels which engages a rack located in the center of the track, so that on heavy grades slippage is obviated and a high tractive effort is obtained.

### THE STORAGE BATTERY LOCOMOTIVE

The use of storage battery locomotives is coming into extensive use, especially since marked improvements have been made in storage batteries within the past few years. When accumulators were first developed, the weight for a given output of current was out of proportion and the battery was to a certain extent fragile and liable to breakage, but some of the modern types not only withstand rough usage but have exceptionally large output for a given weight. See Fig. 20.

As a usual thing two motors are used on this type of locomotive, each directly connected to a driving axle. The great advantage in the use of storage batteries for this work is that no trolley wire is required and the machine can go and come wherever the track is laid, regardless of connection with an outside source of current.

The chief objection to these machines is that they must receive regular charges and therefore be out of service part of the time. The storage battery machines are built in sizes from two to ten tons and several makes of batteries can be supplied with any standard locomotive. Thus the buyer is enabled to choose to some extent the battery he intends to use.

The cost per charge for a storage battery locomotive depends, of course, upon the size and the type of battery used, as well as

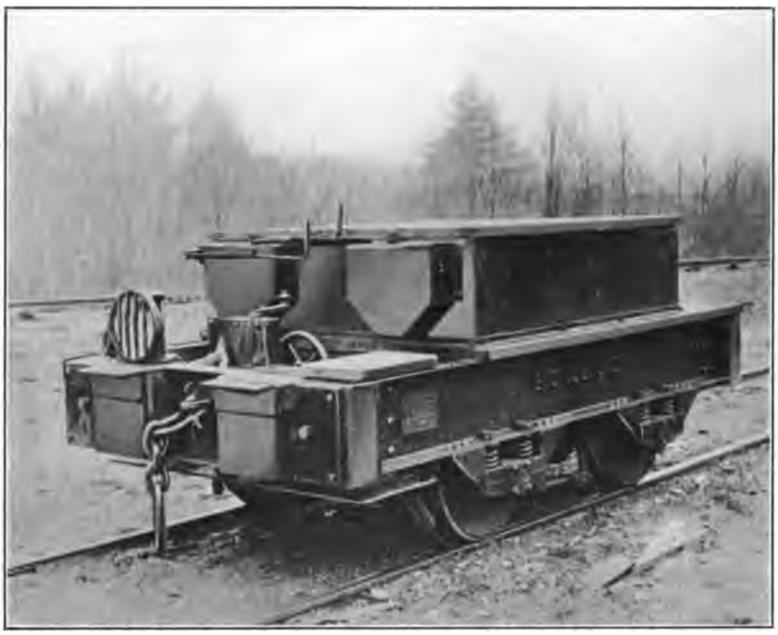

FIG. 20.—General Electric Storage Battery Locomotive.

upon the source of power and the efficiency of the charging equipment. The frequency of charge depends upon the conditions to be met, upon the load hauled and the number of hours per day in use. The number of ton miles it is possible to secure from one of these machines upon one charge ranges from 100 to 200 at a speed from two to five miles per hour.

It is advisable in many cases to place a watt meter or ampere hour meter on an electric locomotive in order to check operating efficiency and determine if the operator uses sufficient care in

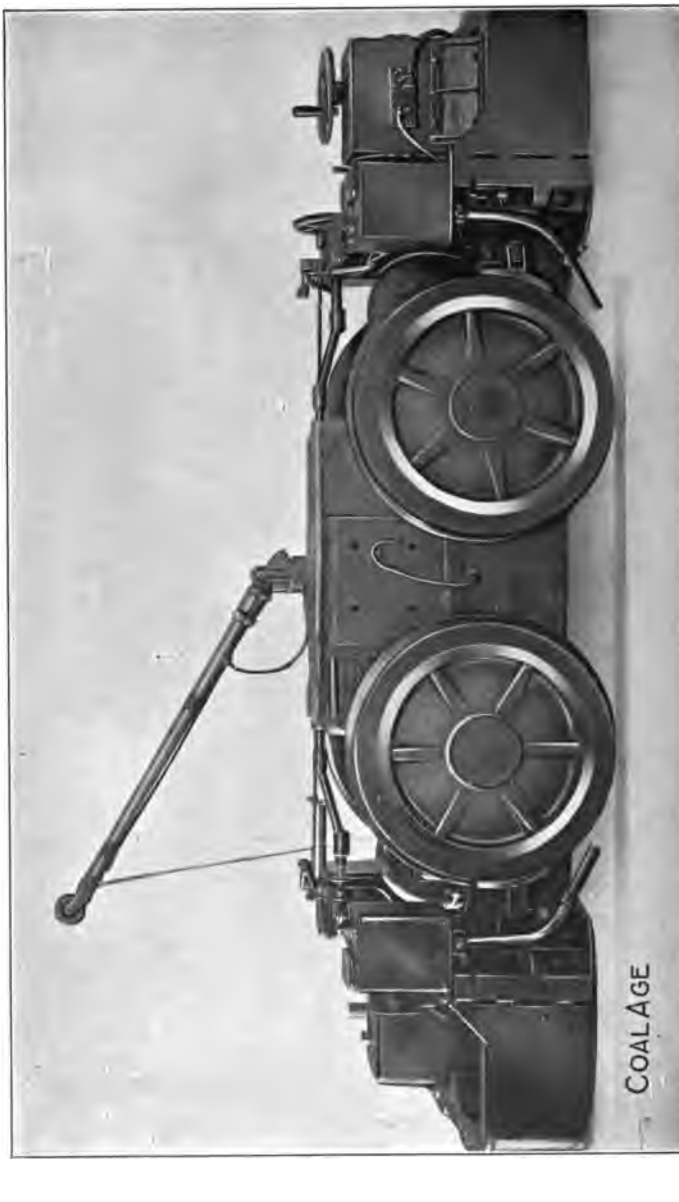


FIG. 21.—Goodman $7\frac{1}{2}$-ton Locomotive.

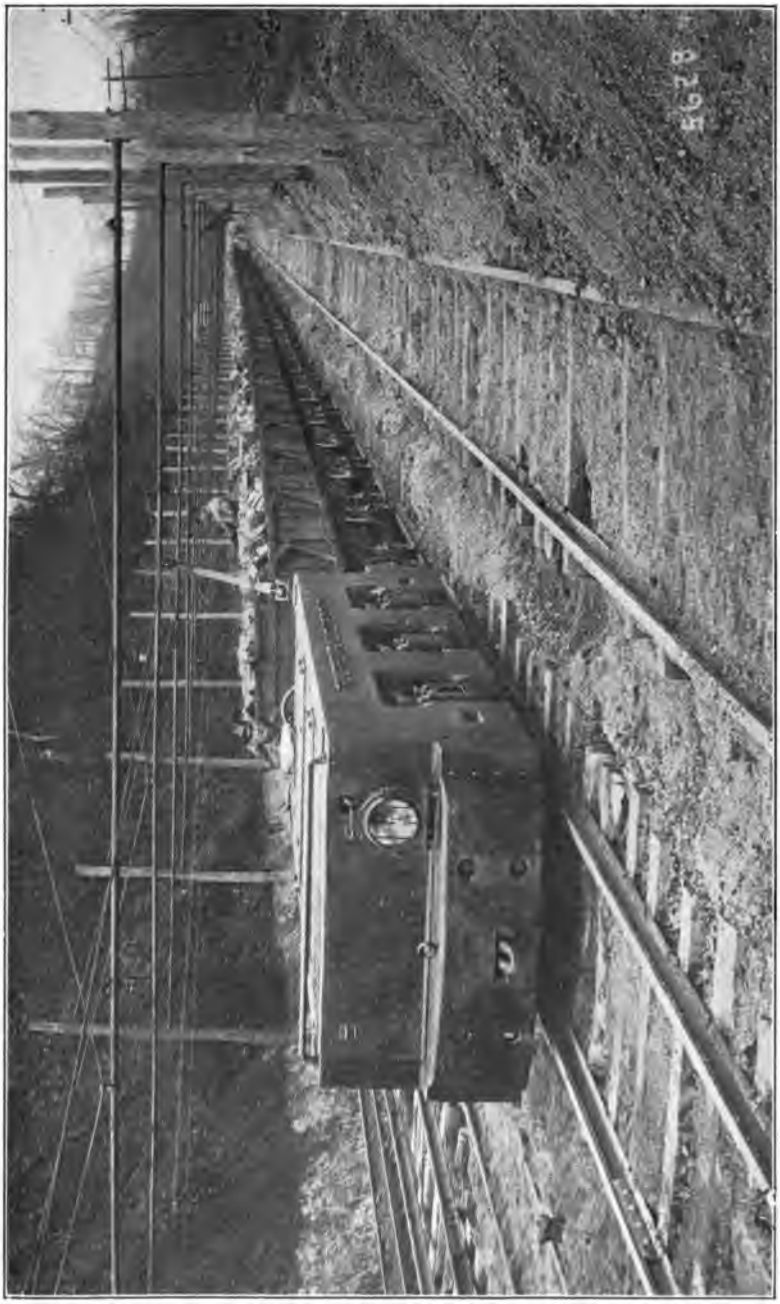

FIG. 22.—Jeffrey Locomotive Hauling Loaded Trip.

conserving current. A registering instrument of some kind is especially necessary on storage battery locomotives since this instrument forms the easiest method of determining when the machine needs a fresh charge.

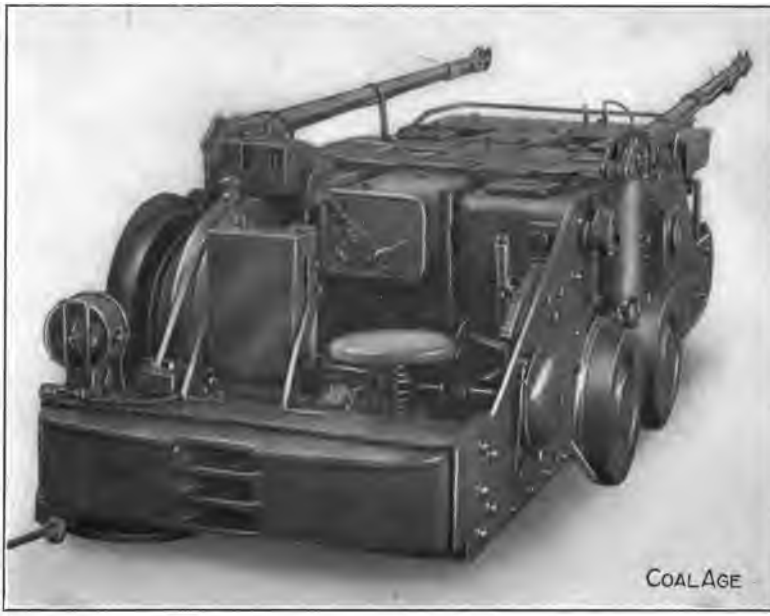


FIG. 23.—Goodman Gathering Locomotive.

Several illustrations showing locomotives of the types mentioned accompany this article and much valuable information may be secured from the manufacturers covering the details of these machines, operating characteristics and cost per ton mile of haulage.

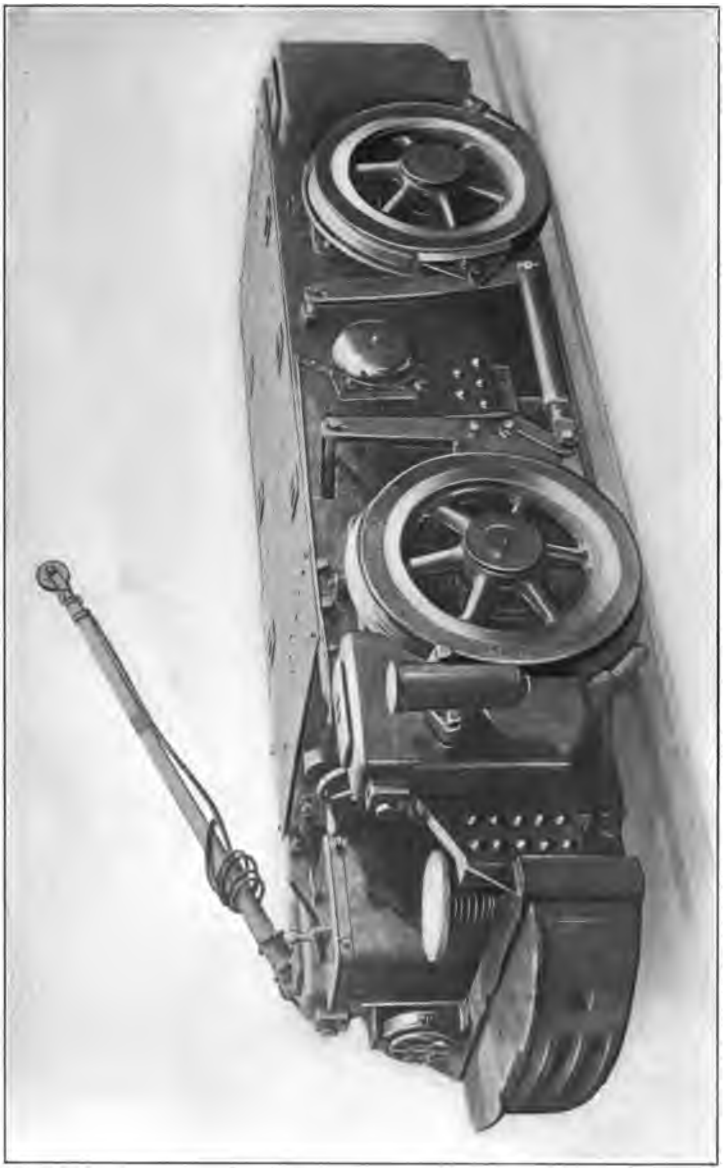

FIG. 24.—Goodman 8-ton Locomotive.


FIG. 25.—Jeffrey Gathering Locomotive.

## CHAPTER X

### COAL-CUTTING MACHINERY

Many types of coal-cutting machines have been developed and placed in operation within the last few years. At first these were built of the pick type driven by compressed air in which the operation of the machine was much like that of pick-work by hand, but since such machines must stand extremely hard usage and be subject to operation by unskilled labor, many changes have been made since the original machines were brought out.

Compressed air has been used with several types of coal-cutting machines but has been replaced by electric power in the more highly developed types. Cutting machines are made in several forms for operating under different conditions upon various kinds of coal and are used in diverse methods of mining. The chief forms in use at the present time are the chain breast, short wall, under cutting, over cutting, turret and combination machines.

The chain breast machine, consists essentially of two parts, a rigid iron frame held in place on the floor by jacks, and second an endless cutter chain traveling over sprockets driven by an electric motor attached to the main frame. This motor serves the purpose both of running the cutter chain and of forcing the entire frame of the machine along the rigid guides upon which it runs. Attached to this endless chain are inserted steel bits which cut a gash through the coal in the same manner that a saw cuts through wood. The depth and breadth of the cut may be varied as well as the speed of feeding.

The machine is operated by placing it on a truck and hauling to the location at which the cutting is to be done where it is either pushed off from the machine or blocked in a working position. Some manufacturers use compound motors for general use on chain breast machines while others employ series motors.

The machines are made in several different sizes, cutting from

5 to 7 ft. in width at a rate of 7 to 40 ins. per minute. Some recent improvements in breast machines consist in adding a self-propelling truck to the regular equipment utilizing the motor which operates the machine to actuate the driving wheels. When the cutter is placed on the truck a temporary sprocket chain is used to connect the motor with the truck wheels and in this manner the machine and truck may be propelled along the regular track to any part of the mine.

Electricity for operating the motors of cutting machines may be fed to them in various ways, the simplest method probably being the use of a duplex cable which is wound up and unwound in a manner similar to that used on an electric gathering locomotive. Sometimes the truck on which the mining machine is moved from place to place carries a trolley pole from which current may be secured. Another method is by the use of a hand trolley which is connected to the controller of the machine and held in contact with the bare wire by one of the attendants. A machine of this type is shown herewith.

### THE SHORT WALL MACHINE

Another cutter which is used to a large extent is the short wall mining machine. See Fig 26. This type of cutter is usually very rugged in design, comparatively simple in operation and rapid in work. The machine uses its own power for practically every operation necessary. It is moved from place to place by a self-propelled truck actuated by a temporary connection with the motor of the machine itself. Unloading is done by means of the feed rope or chain which is fastened to a jack suitably placed so that the machine in winding up the rope drags itself off the truck and up to the face of the coal.

In cutting, the short wall machine is drawn ahead by the feed rope and guided by the tail rope, and cutter arm entering the coal and the guard telescoping into the base of the machine. After sumping, the machine makes a cut across the face of the coal, mining to the full depth of the cutter. After a running cut is finished the machine is dragged out from the coal, across the floor and back onto the truck by the use of the feed rope employed as in unloading. See Fig 27.

These machines are very compact and may be operated even in places where props are necessary without inconvenience. The short wall machine as well as the chain breast machine cuts close to the floor or in case a layer of clay is found beneath the coal a cut may be made entirely under the seam. See Fig. 28. In some machines the feed control is varied by means of friction while the motor is directly connected to the cutters. The operating ropes, namely, the feed and tail ropes, are of flexible steel and are paid off a drum under adjustable control. The tail

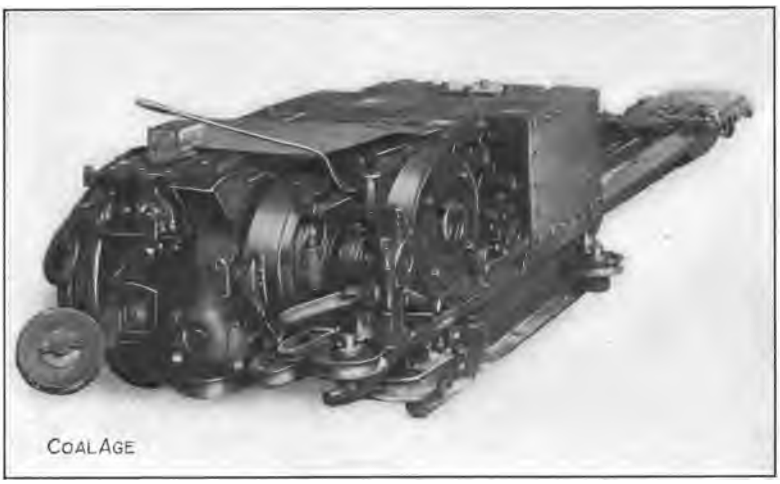


FIG. 26.—Goodman Flame Proof Shortwall Machine.

rope governs the cutter arm position while the feed rope pulls the cutter along through the coal.

The controller used on these machines is similar in construction to those used on mining locomotives and is usually of the drum type.

One of the more recent machines is a combination of the shortwall and longwall type. This machine owing to the arrangement of guide pulleys and swivel cutter can be used in either method of cutting, hence is of considerable value in some mines requiring both forms of undercutting.

The undercutting machine in several forms filled a long felt want in coal mining circles when first placed upon the market


Fig. 27.—Goodman Shortwall Machine, Unloading.

but some conditions in several localities could not be met in an adequate manner by undercutters alone as operators were not long in discovering. A need was apparent for a cutter so constructed as to be able to make a cut at almost any plane between the floor and roof.

FIG. 28.—Machine Undercutting 4 ft. Coal.

As an answer to the call for a machine of this type many forms of overcutters were brought out by the manufacturers in a very short time and are proving eminently satisfactory in several modern operations. These machines are usually operated on the track without unloading, as is necessary with the shortwall cutter, and are nearly all self propelled by a motor on the trucks. The cutter bar swings in the arc of a circle on some machines and the cutter is driven by a motor on the turret framework. The turret motor and cutter are adjustable and

may be raised to any height above the floor up to five feet or more.

When preparing for a cut the machine is run up to the face on a track and is blocked in position. In most cases one jack only is required. The machine is advanced until the cutter has penetrated to the full depth on the right rib. The cutter bar is then swung around in the arc of a circle by means of a friction feed drive making a cut across the face, after which the jack is removed and the machine proceeds under its own power to the next place, the whole operation requiring a very few minutes. The cutter is raised or lowered to the proper height by its own power transmitted through another friction clutch.

Another overcutter has been produced which very similar to a shortwall machine except that the cutter is carried on a special form of truck and may be raised and lowered to almost any position in the seam. This device requires the use of a locomotive in moving from place to place and in making a running cut.

The turret cutters are very rigidly constructed and remarkably rapid in operation. The friction clutch feeds make it almost impossible to stall or break the cutters or bar as the clutch slips under abnormal operating conditions.

Some of the advantages of overcutting are that seams of dirt or shale may be cut out at any height above the floor leaving the coal clean when shot down. This method of cutting out dirty seams often obviates washing the coal besides producing more lump. By running a top and middle cut very light shots may be used with no danger of injury to a tender roof. Less fines are produced by light charges since a heavy charge tends to crush the coal to some extent.

A point not to be overlooked is that a much greater output is possible if overcutting can be done in the proper manner and much time is saved in moving from place to place since loading and unloading is unnecessary in the case of most overcutters.

Cutting machinery is of course a necessity in almost every mine, but probably no one type of machine is adequate for all coal mining conditions to be encountered. There are varying degrees of hardness, variations in the seams and other factors which make necessary the use of more than one type of machine.

For instance there may be places in the same mine requiring both overcutting and undercutting or shortwall cutting in order to produce most efficiently and most rapidly.

In driving ahead or cutting entries use is made in many mines of a combination air-electric machine which operates in a manner similar to an ordinary rock drill, the air being supplied by a small portable electric compressor moved along with the cutter. These machines combine the advantages of both air and electricity and are very efficient in the work for which they are intended. Several sizes are available from the small hand machine to the heavy coal punchers held in position by jacks.

Very recently manufacturers have turned their attention to devising alternating-current motors suitable for driving the many types of coal cutters and some really excellent machines have been produced equipped with this kind of motor. Several advantages are inherent to the alternating current motor, especially the squirrel cage type, since there are no open contacts, no armature to burn out, and no commutator to look after. Either a compensator or star delta connection may be used to start these motors and in both cases the wiring is very simple.

Since these alternating machines have been produced it is possible to fully equip a mine for operation on three phase current, for locomotives, fans, pumps and hoists have all been adapted to this form of power for some time. A small transformer substation is all that is required, if power is available from central station or transmission lines, to furnish electricity for every mining operation.

Where conditions are at all favorable to the use of electrical mining machines or coal cutters in one or more of the many forms their use will enormously increase output if adequate facilities are at hand for removing the increased tonnage without creating a congested condition on the haulage tracks or at the shaft.

# CHAPTER XI

## ELECTRICITY FOR OPERATING FANS AND PUMPS

It has been necessary since almost the earliest developments in coal mining to use some type of device for securing a circulation of air throughout the different parts of the mine. Since both men and animals are working underground in comparatively restricted quarters the oxygen would soon be consumed from the air and replaced by gases dangerous to health and life, even if gas were not constantly escaping from the coal in many mines.

The earliest systems of mine ventilation were based on the principle of chimney suction. Tall stacks were built from which an air duct led into the mine so that when fires were kept burning in the chimney a continual draught of air was being sucked out of the workings and carried up the chimney.

This method was necessarily both cumbersome and expensive and was soon replaced by large fans and blowers driven by steam engines or some other form of power. If steam engines were used and the fans located at a distance from the boiler, larger losses from condensation occurred in the steam pipes. The normally low speed of the steam engine made necessary the use of very large fan wheels which called for expensive housings and heavy foundations.

Upon the advent of electrical power for mine operation the electric fan rapidly came to the front and at the present time it is used almost exclusively where current is available. Electrically driven fans are of many different forms and operated by various types of motors connected in some cases by belts, chains or gearing or more usually mounted on the motor shafts.

When a ventilating fan is of such design that it may be mounted in this manner a high efficiency is secured with practically no noise and very smooth operation. Since a fan must be operated continuously a small gain in economy means a considerable saving in power consumption and since even a short stoppage of the fan would result in danger to those work-

ing in the mine, it is necessary to have the very best driving equipment possible.

The direct connected motor meets these conditions admirably for not only is it economical but subject to little danger from accident or wear. The motor-driven fan being usually run at high speed is compact and easily moved when necessary. When a change of location is found to be desirable, the feed wires may be quickly taken down and erected at a different point.

If electric power is available and a fan be subjected to some accident, it is possible to install temporary equipment quickly, fed from the distributing lines to take the place of the disabled machine.

Where alternating current is available perhaps no better method of driving a fan may be found than the use of a squirrel cage induction motor since these machines have no open contacts, no sliding brushes or commutator, and consist of only two parts, the roter or rotating member and the stator or machine frame upon which the windings are placed. Such a motor will operate continuously and economically with practically no attention except an occasional oiling. Direct current motors, however, are quite satisfactory in several types when alternating current is not available.

### PUMPS ALSO HAVE HARD, ROUGH USAGE

Another class of mining machinery upon which devolves hard service is the mine pump. Pumps are placed in service for two purposes, to supply water to the boilers or for domestic use and to pump out the water accumulating in the lower levels of the mine.

Many different types of pumps are found in common use, the geared, single action, duplex, triplex and multiplex, centrifugal and positive rotary. Each of these types has certain advantageous points for working under certain conditions and it may be necessary to use several types in one mine to meet the varying requirements. Probably the most satisfactory pump for domestic and boiler service is the plunger type, either simplex or duplex, operated through spur gearing by an electric motor.

Here again the induction motor makes an excellent driving power since it operates smoothly and with practically no attention. This machine is less affected by dampness than any other type and cases have been known where a squirrel cage motor continued to operate after being submerged by several feet of water for five days or until it had pumped all the water out of the shaft in which it was located and this without injury either to the motor or to the pump.

It is possible to use a motor on a small pump that may be thrown directly across the line without injury but those of a larger size require some form of starting device. This may be either hand operated or entirely automatic. Thus, a pump may be located at a long distance from the power house and yet be readily controlled from this point.

In the case of domestic water supply the operation of the pump may be made entirely automatic by a float switch mechanism so that when the water drops to a certain level in the tank the motor is automatically started and pumps until the tank is filled to a predetermined point where the float throws out the switch and stops the pump. Frequently an arrangement of this kind is used in the lowest level of the underground workings so that when water rises in the sump to a given point the motor begins work and pumps the water out without any attention whatever.

### PISTON PUMPS ARE SUBJECT TO RAPID WEAR

Although the piston pumps are quite efficient in handling water, they are subject to rapid wear from mud or grit and frequently a few months operation either wears out the valves or cuts the cylinder so badly that a new pump is made necessary. To obviate these troubles, many types of centrifugal pumps have been brought out in which there are no valves and no sliding surfaces exposed to the gritty water.

The principle of operation in these pumps is as follows: The pump casing being full of water the impeller in rapid motion tends to throw the water outward by centrifugal force, and as the only outlet is the delivery pipe at some point in the circumference of the casing, the water is forced out through this

opening with considerable velocity and is replaced by suction with more water admitted to the center of the impeller.

One marked advantage in this type of pump is that owing to a high speed being necessary they may be connected directly to an electric motor shaft without intermediate belting or gearing. Many of these pumps are mounted direct on the motor base so that the whole forms a self-contained unit and may be moved from place to place readily.

A peculiar feature of the centrifugal pump and one that is directly opposite to that which exists in the piston or plunger type is that when the discharge pipe gate-valve is closed the pump impellor runs light and without taking excessive power, but as soon as this valve is opened the pump assumes a load. If the gate-valve were closed on a plunger pump when it was running, either the pipe or pump would be broken or the driving power would be stalled since such a pump is positive in action.

Another type of pump used to some extent where pure water is to be forced from one level to another is the postive rotary pump which usually consists of some form of gearing or wheels which mesh together in such a manner as to create a suction in one side of the casing and a pressure in the other. This type of pump runs at a higher speed than the piston pump but lower than the centrifugal and is not employed to any great extent in mine work.

As a usual thing it is advisable to use a motor about twice the size theoretically necessary to drive a given pump since considerable losses occur both in the pump proper and the pipe lines. If the pump is of the piston type driven by intermediate gearing considerable power is lost in the transmission, so it is best to dispense with all gearing except that absolutely required.

The theoretical power necessary for pumping purposes may be found as follows; multiply the height of head in feet by the number of gallons to be moved per minute and this product by 8 1/3, dividing by 33,000. This gives the theoretical horse power which should be multiplied by 2 in order to find the size of motor necessary.

# CHAPTER XII

## THE REPAIR SHOP

Practically every well-regulated mine has, or pretends to have, some kind of a repair shop. Most of these shops make no pretense of being complete or equipped with machinery found desirable in making any but the most simple repairs. Very few have a stock of material from which to select repair parts and most of them are operated by men who are not acquainted with modern practice in armature and machine work.

Such a shop is a doubtful benefit for much of the work turned out is inferior, both in material and workmanship and fails to give satisfactory service under operating conditions. So much is wasted in time and material that frequently it is better to have such work done at a fully equipped plant, even if some delay is incurred by having repairs made at a distance from the mine.

If a repair shop is desired, however, it is best to have one fairly well fitted with machinery tools and supplies. After which a man competent to do machine work and experienced in repairs to be found in a mining operation should be placed in charge of the work. If this is done, it is possible to turn out creditable work within a reasonable length of time, and in an economical manner.

After the shop is in running order all the machinery operated at the mine should be kept in first-class condition and the necessary repairs made the instant there is sign of wear or breakage. If the regular inspection of the equipment is made at frequent intervals and a report of any defect or bad adjustment promptly turned over to the machinest in charge, it is possible to prevent any serious accident occurring to the mechanical equipment; thus much expense can be obviated as well as delays to the entire mine occasioned by burnouts in the windings or breakage in the machinery.

Few machine tools are absolutely necessary but among the essential items may be mentioned a heavy drill press, a lathe

which will swing all the armatures used at the mine with the exception of those in the generating units, a small shaper, a grinding head equipped with emery wheels, a forge and blower attachment with a small set of blacksmiths tools and suitable arrangements for driving these machines. A fairly complete set of small tools will be found necessary, such as hand drills, hack saws, files, a carpenters kit and convenient racks or receptacles for preventing loss of the smaller implements.

In the armature-winding department should be kept a fairly complete stock of all the magnet wire found on the machines used at the mine together with linen tape, micabond, sheet fiber, insulating paint, binding wire, flexible lead wire and fish paper. Adequate arrangements should be installed for testing the armatures after they are wound in order to locate grounds or shorts before making a running test.

It is a good plan if possible to have some spare armatures of the sizes used about the mine and frequently spare motors will be found to fit in nicely when accidents occur to the driving equipment of fans and pumps. A reasonable supply of bus-bar copper, sheet and bar iron and brass rods should be kept in stock so that many of the small fittings on machines which are liable to accident may be made up in short time if required.

A complete inventory of all the tools, raw material, supplies and renewal parts should be kept in the office and checked over occasionally as one of the most serious drains on a shop of this kind is the loss of tools and material from theft or carelessness.

If a repair shop similar to that outlined above is placed in operation under a capable man it may be made a source of much satisfaction and saving in money to any mining plant. But if it is to receive only the care usually given to shops of this nature, it would be better to send all the repairs to some regular machine shop even if delays and losses are incurred by such a course.

## CHAPTER XIII

### THE FUNDAMENTALS OF EFFICIENT OPERATION

To the coal operator seeking larger returns on the investment and a more satisfactory operation from a pecuniary standpoint there are three and only three possible solutions to the problem: to sell at a higher price per unit, to produce and market at a lower cost per unit or to turn out a larger quantity of coal at the same producing cost and selling price as formerly.

The first method, that of securing a larger profit by increasing the selling price per unit (this unit in the case of coal of course being the ton) is not generally feasible on account of competition and market conditions, hence is eliminated from this discussion. The only possible chance for selling at a higher price is to produce a better quality of coal than competing firms or create a belief in the consumer's mind that there is some special advantage in using this particular brand of coal at a higher price.

Notwithstanding this, however, the writer purposes to show how in his opinion 95 percent of coal-mine operators may increase their production without additional outlay and at the same time reduce the unit cost of operation.

Many factors naturally enter into results of this kind, but if any one factor be greatly improved then the whole result is bettered in proportion to the importance of that one changed factor. Thus, if we operate continuously at maximum output without delay or stoppage of production, we increase the tonnage of the average mine, for in practically every instance there are some days lost each month in nearly every mine and probably a great many days in which the output is reduced to some extent by a cause which could have been prevented.

Again if we cut our repair bills materially, we reduce the unit cost of production by lowering our overhead expense in the proportion that repair costs bear to the entire overhead charges. This item of overhead expense is one that offers every

inducement for reduction to the lowest possible point since it is a constant drain on the finances of the company and continues even though the operation is shut down.

It is possible then to increase the earning capacity of the average mine by an alteration of these two factors, that is to secure continuous operation and to reduce upkeep expense.

If we examine the causes tending to produce delays and cessation of operation we find that burnouts of motor and generator windings and breakdowns in the power house equipment and rolling stock are the most frequent of these troubles and strange to say are the most easily prevented. A breakdown imposes two burdens on the efficiency of the mine; a delay in production and a repair expense, and for this reason should be most carefully guarded against.

While you, the reader, are considering this problem, estimate the monthly saving you might make in your own mine if breakage and burnouts could be prevented in even three-fourths of the instances that such accidents occur. It will surprise you, no doubt, and you will begin to realize that an increase in the efficiency of production is not only possible but may be actually secured by a careful attention to details. The writer does not believe that any mine or industrial plant can be operated without some breakage but there is a minimum which can be secured and maintained but which is rarely found in mining practice.

To begin with, the plant should be carefully designed by one cognizant of the duties to be imposed upon it, of adequate size for the work to be done and properly installed. If this is not the condition in any plant under consideration, it means an increase in efficiency and more satisfactory operation for the equipment to be brought up to such a standard.

In the second place, it is necessary in order to secure the highest economy that all repairs be made before actual breakage and before a complete shutdown is necessitated. If one coil is burned out in an armature, that coil should be repaired before it injures those lying next to it and thus save a complete rewinding, or, if a commutator is nearly worn out, a new one should be secured and be put on the machine before the old

one goes entirely to the bad, burns up the armature and absolutely disables the unit.

Troubles must be corrected in the very beginning for one bad operative condition leads to another and that to another until the entire plant may be down for a week on account of something that could have been corrected in 10 minutes if handled at the right time. Prevention, although not possible in every case, is far more economical than paying large repair bills, especially when small repairs may be made at the mine without trouble and larger ones call for outside assistance.

The trouble with a great many mine superintendents and their electricians is that they have an idea that it is economy to run any machine as long as a wheel will turn regardless of conditions or the state in which the machine is operating. The writer has seen a motor taken in on a haul when there was almost a certainty that it would burn out on the first heavy pull. This it did, although a half hour's repair work on one of the coils before it entered the mine would have saved a complete rewinding, several day's labor and the loss of the use of the machine.

How can efficient production be secured while operating under such methods and when those in charge have such peculiar ideas regarding economical production?

To secure the most satisfactory operation of mining equipment, the engineer or electrician should be required to make a daily inspection of every piece of machinery in operation and submit a written report, carefully noting any troublesome condition, no matter how seemingly insignificant. These defects should be attended to immediately, or, if it is not possible to effect a satisfactory repair at once the machine should be withdrawn from service until the troubles are remedied and have been so reported. If the electrician is too busy, or lacks the knowledge necessary for making an accurate report daily, it is well to have monthly reports furnished by some outside engineer. These reports should be in detail, with notation on the operation, physical condition and probable life of every piece of machinery, especially those showing wear or giving the attendant trouble. A list of duplicate parts should be furnished by

the man making the inspection and these parts should be ordered and kept in stock ready for instant use. At least once each month these repair parts and duplicates should be checked over and any that are missing or have been used should be replaced as soon as possible.

A routine of this kind may seem irksome to the superintendent and in all probability the mine electricians and engineers will object strenuously to the added work but the operator should overrule these objections in order to keep down expense and run the entire plant at full production.

The supply salesmen are not going to assist the plant toward economical operation for they wish to sell more supplies; the outside armature winders, machinists and repair men are not inclined to help for they wish something to do, the machinery salesman is bent only on selling new equipment to replace that worn out. It is up to you, the operator, the superintendent, to introduce an adequate system of inspection and careful maintenance, if an increased output is desired at a reduced unit cost of production, meaning larger dividends.

## APPENDIX

Ohms's Law, as applied to direct-current calculations

$$I = \frac{E}{R} \text{ or } R = \frac{E}{I} \text{ or } E = IR$$

Power formula for direct current

$$P = I \times E \text{ or } P = \frac{E^2}{R} \text{ or } P = I^2R$$

$$I = \frac{P}{E} \text{ or } I = \sqrt{\frac{P}{R}} \text{ or } E = \sqrt{R \times P}$$

$$R = \frac{E^2}{P} \text{ or } R = \frac{P}{I^2}$$

Where

$E$ = Electro-motive force or voltage
$I$ = Current in amperes
$R$ = Resistance in ohms
$P$ = Power in watts.

Ohm's Law, as applied to alternating current calculations

$$I = \frac{E}{\sqrt{R^2+r^2}} \text{ or } E = I \times \sqrt{R^2+r^2} \text{ or } \sqrt{R^2+r^2} = \frac{E}{I}$$

Power formula for alternating current:

Single phase

$$P = E \times I \times p.f. \text{ or } E = \frac{P}{I \times p.f.} \text{ or } I = \frac{P}{E \times p.f.}$$

Three phase

$$I = \frac{P}{P \times \sqrt{3}} \text{ or } E = \frac{P}{I \times \sqrt{3}} \text{ or } P = E \times I \times \sqrt{3}$$

where power factor is unity

$$I = \frac{P}{E \times \sqrt{3} \times p.f.} \text{ or } E = \frac{P}{I \times \sqrt{3} \times p.f.} \text{ or } P = \sqrt{3} \times I \times E \times p.f.$$

where power factor is less than unity
when

$E$ = Electro-motive force or voltage
$I$ = Current in amperes
$R$ = Resistance in ohms
$P$ = Power in watts
$r$ = Reactance
$p.f.$ = power factor or $\cos \phi$ when $\phi$ = angle of lag.

## ENGINEERING DATA

### Table of Multiples

Diameter of a circle × 3.1416 = circumference.
Square of the radius × 3.1416 = area.
Square of the diameter × .7854 = area.
Diameter of a circle × .86 = side of inscribed equilateral triangle.
Diameter of a circle × .7071 = side of inscribed square.
Base of triangle × half the altitude = area.
Circumference of a sphere × diameter = surface.
Surface of a sphere × one-sixth its diameter = volume.
Cube of the diameter of a sphere × .5236 = volume.

### Wire Tables

Allowable Carrying Capacities of Wires, N. E. C. Standard.

| Table A. | | Table B. | |
|---|---|---|---|
| Rubber Insulation. | | Other Insulations. | |
| B. & S. G. | Amperes. | Amperes. | Circular Mils. |
| 18 | 3 | 5 | 1,624 |
| 16 | 6 | 10 | 2,583 |
| 14 | 15 | 20 | 4,107 |
| 12 | 20 | 25 | 6,530 |
| 10 | 25 | 30 | 10,380 |
| 8 | 35 | 50 | 16,510 |
| 6 | 50 | 70 | 26,250 |
| 5 | 55 | 80 | 33,100 |
| 4 | 70 | 90 | 41,740 |
| 3 | 80 | 100 | 52,630 |
| 2 | 90 | 125 | 66,370 |
| 1 | 100 | 150 | 83,690 |
| 0 | 125 | 200 | 105,500 |
| 00 | 150 | 225 | 133,100 |
| 000 | 175 | 275 | 167,800 |
| 0000 | 225 | 325 | 211,600 |

| Circular Mils. | | |
|---|---|---|
| 200,000 | 200 | 300 |
| 300,000 | 275 | 400 |
| 400,000 | 325 | 500 |
| 500,000 | 400 | 600 |
| 600,000 | 450 | 680 |
| 700,000 | 500 | 760 |
| 800,000 | 550 | 840 |
| 900,000 | 600 | 920 |

**Wire Tables.**—*Continued.*

| Circular Mils | | |
|---|---|---|
| 1,000,000 | 650 | 1,000 |
| 1,100,000 | 690 | 1,080 |
| 1,200,000 | 730 | 1,150 |
| 1,300,000 | 770 | 1,220 |
| 1,400,000 | 810 | 1,290 |
| 1,500,000 | 850 | 1,360 |
| 1,600,000 | 890 | 1,430 |
| 1,700,000 | 930 | 1,490 |
| 1,800,000 | 970 | 1,550 |
| 1,900,000 | 1,010 | 1,610 |
| 2,000,000 | 1,050 | 1,670 |

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

### How to Remember the Wire Table

A wire which is three sizes larger than another wire has half the resistance, twice the weight and twice the area. A wire which is ten sizes larger than another wire has one-tenth the resistance, ten times the weight and ten times the area.

No. 10 wire is .10 in. diameter (more precisely .102); it has an area of 10,000 circular mils (more precisely 10,380); it has a resistance of 1 ohm per thousand feet at 20 deg. C. (68 deg. F.), and weighs 32 lb. (more precisely 31.4 lb.) per thousand feet.

The weight of 1000 ft. of No. 5 wire is 100 lb.

The relative values of resistance (for decreasing sizes) and of weight and area (for increasing sizes) for "consecutive" sizes are: .50, .63, .80, 1.00, 1.25, 1.60, 2.00.

To find resistance, drop one cipher from the number of circular mils; the result is the number of feet per ohm.

To find weight, drop four ciphers from the number of circular mils and multiply by the weight of No. 10 wire.

### To Determine Size of Copper Wire for Any Given Service

Let

$CM$ = Circular mils
$D$ = Distance in feet
$I$ = Current in amperes
$L$ = Loss in volts.

21.6 is a constant or figure always used. Then

$$CM = \frac{I \times D \times 21.6}{L}$$

**Ohm's Law**

$I$ = Current in amperes
$E$ = Electromotive force
$R$ = Resistance in ohms
$W$ = Energy in watts.

$$I = \frac{E}{R} \qquad E = I \times R \qquad R = \frac{E}{I}$$

$$I \times E = W \qquad W = \frac{E^2}{R} \qquad I^2 \times R = W$$

$$\frac{W}{746} = \text{h.p.} \qquad W = 746 \times \text{h.p.}$$

**Equivalents of Electrical Units**

(HERING)

1 Kilowatt = 1000 watts.
1 Kilowatt = 1.34 h.p.
1 Kilowatt = 44,257 ft.-lb. per minute.
1 Kilowatt = 56.87 B.t.u. per minute.
1 Horse power = 746 watts.
1 Horse power = 33,000 ft.-lb. per minute.
1 Horse power = 42.41 B.t.u. per minute.
1 B.t.u. (British Thermal Unit) = 778 ft.-lb.
1 B.t.u. = .2930 watt-hours.

**Heat Units**

(FOSTER)

One pound of water evaporated from and at 212 deg. F......
- .283 kw.-hr.
- .39 h.p.-hr.
- 966 B.t.u.
- 751,300 ft.-lb.
- .0664 lb. carbon oxidized at 100% eff.

1 H.p.-hour..................
- 2545 B.t.u.
- .746 kw.-hr.
- 1,980,000 ft.-lb.
- .175 lb. carbon oxidized at 100% eff.

1 Kw.-hour .................. $\begin{cases} \text{.235 lb. carbon oxidized at 100\% eff.} \\ \text{22.8 lb. water raised from 62° to 212° F.} \\ \text{3.53 lb. water evaporated at 212° F.} \\ \text{3412 B.t.u.} \\ \text{2,654,200 ft.-lb.} \end{cases}$

### Convenient Formulæ

#### Hydraulics

Pound per square inch = .434 times head of water in feet.
Head in feet = 2.3 × pounds per square inch.
Weight per cubic feet of water = 62.4 lb.
Weight of gallon of water = 8.33 lb.
Loss of head $H$ due to friction in pipes.

$$H = \frac{.02 \times L \times V^2}{64.4D}$$

$L$ = Length of pipe in feet; $D$ = diameter in feet; and $V$ = velocity of flow in feet per second. In calculating the total head to be pumped against, it is common to consider it equal to the sum of the friction head and the actual head.

### Horse Power of Water-fall

$$\text{h.p.} = \frac{62.4 \times A \times V \times H}{33{,}000}$$

$A$ = Cross section in square feet of stream flowing over dam.
$V$ = Velocity of flow in feet per minute.
$H$ = Head of fall in feet.

# INDEX